FEB 16 1903

Next Meeting Feb. 27th, 1903. Subject: Railway Train Lighting.

Entered as matter of the second class at the New York, N. Y. Post Office, November 26th, 1890.

VOLUME XX.
NUMBER 1. } JANUARY, 1903. Annual Subscription $5.00 Single Copies - .50

TRANSACTIONS
OF THE
AMERICAN INSTITUTE
OF
ELECTRICAL ENGINEERS.

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PUBLISHED MONTHLY (EXCEPTING JULY AND AUGUST) BY THE INSTITUTE, UNDER THE SUPERVISION OF THE EDITING COMMITTEE.

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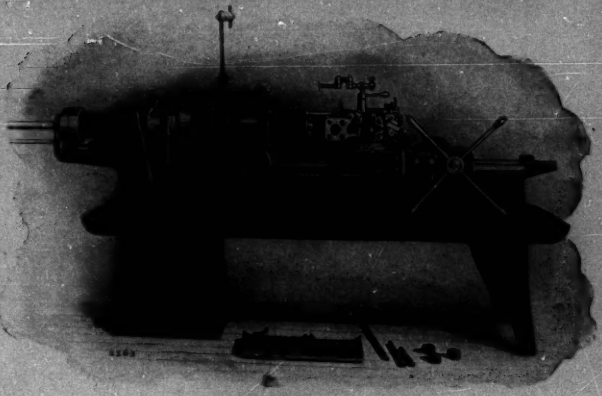

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, December 19, 1902.

The 171st meeting was held this date at 12 W. 31st Street.

President Chas. F. Scott called the meeting to order at 8:15 and said that the Secretary had an announcement to make:

SECRETARY POPE:—At the meeting of the board of directors this afternoon, the following seventeen associates were elected:

Name.	Address.	Endorsers.
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CONRAD, FRANK,	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; residence, Edgewood Park, Pa.	C. F. Scott. H. P. Davis. F. N. Waterman.
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Total, 52.

Transferred from Associate to Full Membership.

Recommended by Board of Examiners, Friday, Oct. 24, 1902.

FRANCIS V. T. LEE, Engineer (Pacific Coast Department), Stanley Electric Mfg. Co., San Francisco, Cal.

HENRY NOEL POTTER, 510 W. 23d St., New York City.

A paper read at the 171st Meeting of the American Institute of Electrical Engineers New York, December 19th, 1902.

BRAKING AND TRACTION BRAKES.

INTRODUCTION BY PRESIDENT SCOTT.

In considering the engineering problems connected with the operation of cars or trains, our minds naturally turn to the positive features. The motive power and the means provided for controlling it while starting or running cars or trains are the matters which at first attract attention. The negative problems, however, are of importance and become of greater moment as weights and speeds increase.

I well remember as a boy the difficulties encountered by passenger trains in stopping at stations. The brakemen were called to the platforms by the engine whistle, but frequently the trains were considerably past the station platforms before they stopped. It was then necessary to back to the station. I remember also learning from a friendly engineer that the engineers of his road insisted that their pay should be increased for the added duties which were to be placed upon them when they would be called upon to do the work of the brakemen through the agency of the air brake.

Difficult braking problems are now being encountered in electric traction. Weights have increased tenfold and speeds on our streets have increased three or fourfold, thereby increasing the stored energy in the car one hundred times, and the old hand brake of the horse car is inadequate. Interurban railways with their still heavier cars and far greater speeds make the problem of braking quite similar to that in steam railway service.

In electric service on elevated and underground city railways, where stops are frequent and high schedule speeds are essential, certain new elements have entered into the braking problem.

Ordinarily, brakes are for the purpose of facilitating traffic and preventing accident. The new feature of commercial value which has come into the problem is that of quick retardation. The run from one station to the next consists in acceleration, running at a sensibly constant maximum speed, and retardation. To increase schedule speed, it is important to lessen the time of retardation as well as that of acceleration. This is a new demand. It presents a new point of view in braking problems which have not previously been of importance in regular service.

This is illustrated by the marked difference which may be made in the schedule speed under average conditions such as prevail on the elevated railways of Greater New York, by changing from a low rate of braking to quick retardation. A change in the rate of retardation from one mile per hour per second to three miles per hour per second, all other conditions remaining exactly the same, increases the schedule speed about 10 per cent. This effects a saving in time to the passengers of 10 per cent., and it reduces the number of trains required for carrying a given number of passengers by 10 per cent.; or what is more important, the same cars may carry 10 per cent. more passengers.

We may divide the brakes in ordinary use into two classes; hand brakes and power brakes. The latter may be again subdivided into air brakes and electric brakes. When the air brake is used on electric cars, electricity is an acceptable auxiliary through the agency of the motor-driven pump.

Electric brakes are of several general types. The motor itself may act as a brake in either of several ways. The motor may be reversed. This is a severe measure which is seldom applied except in an emergency. The motor may be used as a dynamo for absorbing the energy or motion of the car. The power delivered by the motor (or dynamo) may be employed usefully by being returned to the line, in charging a storage battery on the car, or by heating rheostats which are used for heating the car, or on the other hand, it may be wasted in rheostats under the car.

Again, the current from the motor may be used for operating some form of magnetic brake. In this case the car is retarded both by the energy taken by the motor acting as a dynamo and also by the friction produced in the magnetic brake. The brake in this case may consist of two discs one stationary and the other mounted on the car axle, or it may be a track brake in which there is friction between moving shoes and the track rail.

Magnetic brakes may be operated independently of the motors by current obtained from the line or from a storage battery.

These methods indicate various ways in which electricity may be used for braking and make obvious the extreme flexibility of electricity in its application to problems of this kind. The application of the braking effect in proper amount at the proper time and with a reliable method of control, places very exacting requirements upon the designer of braking appliances.

The importance of the braking problem makes it a fitting and appropriate subject for consideration by this INSTITUTE. We may congratulate ourselves upon having to-night two papers, one of which presents the results of tests upon an important city railway, while the other sets forth the general problem of braking in a comprehensive manner and presents the subject in a way which will be of great value to those who have to deal with the design and equipment of braking apparatus and to those who are called upon to determine the requirements and to select the apparatus for particular installations.

A paper read at the 171st meeting of the American Institute of Electrical Engineers, New York, December 19, 1902.

SOME BRAKE-TESTS AND DEDUCTIONS THEREFROM.

BY J. D. KEILEY.

A description of a method of making brake-tests, and of a recording apparatus used in this method; also results from tests on a number of varieties of brakes and an empirical equation showing the operation of these brakes under different conditions, the coefficients entering into the equations being derived from the tests. Illustrated.

On account of the widely varying conditions of electric railway operation, and of the fact that the design of equipment and track has been in a period of evolution from horse-car practice to a condition approximating heavy railroad practice, many branches of the art, especially the subject of braking, have not been developed in the same proportion to their possibilities as has the subject of train-braking with locomotive traction. It is apparent that the conditions of electric traction and the service requirements and constructions which have made desirable, and even necessary, great advances in the methods of braking, have also to some extent rendered these advances possible, and have given to investigators of the subject, as well as users of train- and car-brakes, a new interest and a broader field of activity.

On the braking of elevated and light interurban cars or trains, the aspect of the problem has, of course, been changed from the conditions of locomotive traction—slow acceleration to comparatively low maximum speeds, and the braking of light cars with maximum passenger load equal to 60 or 70 per cent. of weight of cars—to the conditions of electric traction with distributed motors. In the latter case the motors are carried on the passenger trucks, with armatures geared directly to axles; here we find rapid acceleration to high maximum speeds, and the braking of cars with maximum passenger loads equal to but 45 or 50 per cent. of the weight of cars. The rapid acceleration and high maximum speeds with very efficient braking make possible high schedule speeds under conditions of frequent stops. A concur-

rent condition, in many instances of the first importance, is the relation between effective braking and liability to accident. Notwithstanding these changes in mechanical limitations and operating requirements, many small electric railroad companies, and even many very large systems, have apparently been satisfied with old apparatus and have continued to use the single floating lever (or sway bar) inherited from horse-car practice. Another class of users have, at great expense, equipped their cars with novel and complicated apparatus, to be used in developing greater force for the application of brake-shoes to wheels than could be produced with similar dispatch by human muscular effort when applied to brake-wheels or crank-handles. A third

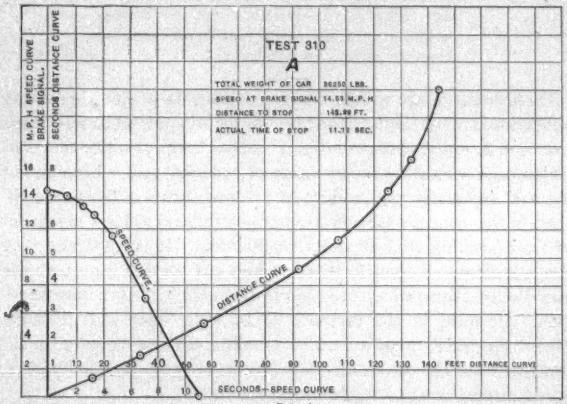

FIG. 1

class of users and a large class of investigators have endeavored to effect the retardation of cars by other means than friction between wheel and rail set up by the pressure of brake-shoes upon wheels.

A class of braking which is of the first importance on account of the very large number of cars in service, and the magnitude of the accident liability affected by them each year, is the emergency braking of cars of from 15 to 25 tons weight (including passenger load), from speeds which are under 30 miles per hour. This class of brake-service is clearly differentiated from what is commonly known as " high-speed " braking, and requires for its accomplishment a different sort of apparatus. Consider, for instance, the case of a double-truck electric car used in city, suburban or inter-

urban runs, or for all three classes of service collectively. This is a very ordinary case, and perhaps the most exacting requirements on the braking apparatus of such a car are those met with in the city or suburban runs, where cars are operated over public highways and unprotected crossings at comparatively high speeds. Under these conditions, emergency stops must often be made, and a braking apparatus is required of sufficient capacity to stop a car that is moving at a rate varying from 15 to 30 miles per hour, and in the shortest possible distance after the motorman receives notice of the necessity of checking the speed.

Such cars are frequently equipped with either merely a hand-brake and a single floating lever (giving anywhere from 25 per cent.

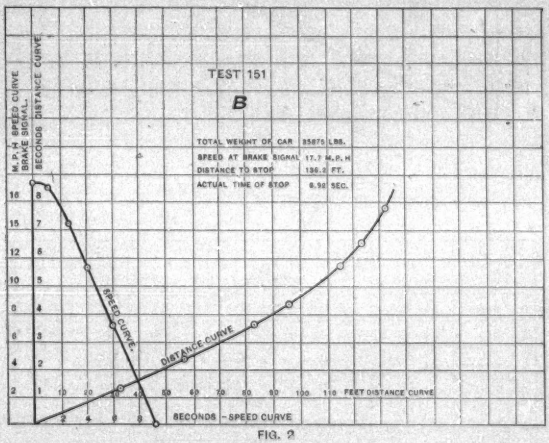

FIG. 2

to 40 per cent. excess brake-pressure on the rear brake); with a hand-brake and some system of equalizing levers; with air, or other power-brake and equalizing levers; or with some power-brake in which, in addition to the friction introduced by a rail-shoe depending for its friction upon a portion of the weight of the car, there is an entirely separate frictional force set up by electromagnetic action between the rail-shoe and the rail. None of this apparatus, except, perhaps, the last mentioned, exhibits any marked advance over the braking of cars used in locomotive traction in city or suburban service.

No attempt will be made in this paper to give a comprehensive summary of the principles and theory of braking, distribution of

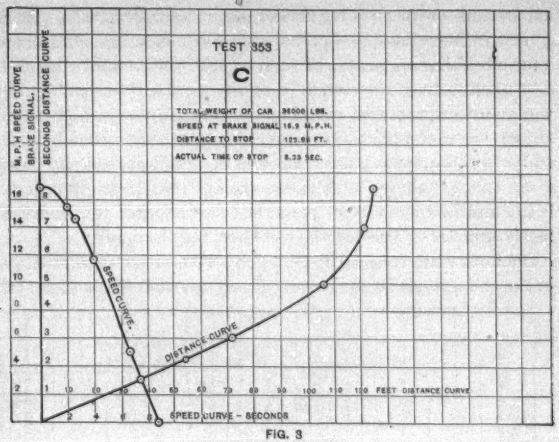
TEST 353
C
TOTAL WEIGHT OF CAR 96000 LBS.
SPEED AT BRAKE SIGNAL 16.9 M.P.H.
DISTANCE TO STOP 125.85 FT.
ACTUAL TIME OF STOP 8.33 SEC.
M.P.H. SPEED CURVE
BRAKE SIGNAL
SECONDS DISTANCE CURVE
SPEED CURVE
DISTANCE CURVE
FEET DISTANCE CURVE
SPEED CURVE - SECONDS

FIG. 3

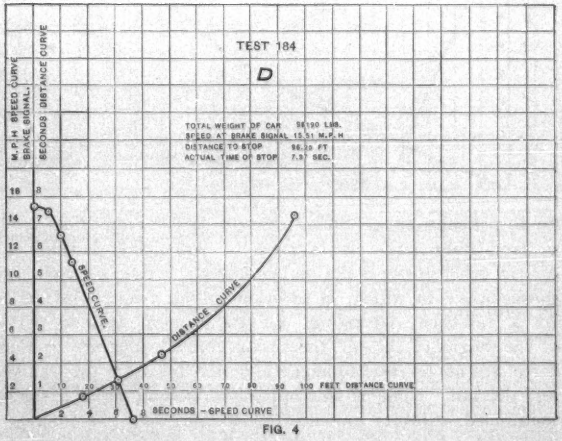
TEST 184
D
TOTAL WEIGHT OF CAR 96190 LBS.
SPEED AT BRAKE SIGNAL 15.51 M.P.H.
DISTANCE TO STOP 98.30 FT.
ACTUAL TIME OF STOP 7.37 SEC.
M.P.H. SPEED CURVE
BRAKE SIGNAL
SECONDS DISTANCE CURVE
SPEED CURVE
DISTANCE CURVE
FEET DISTANCE CURVE
SECONDS - SPEED CURVE

FIG. 4

pressure between trucks or wheels or the design and construction of foundation rigging, or truck rigging. It will contain a brief statement of certain methods which have been used in the determining for an electric traction company the relative merits of several types of power-brakes.

In designing new or investigating existing brake-apparatus, the identity and relative importance of the several consecutive events which occur in the stopping of a car under ordinary conditions should be fully considered. It was thought desirable in the brake tests described below to plot accurately a curve-sheet, such as is shown in Fig. 8, where the distances in which a car can be brought to a stop from different speeds at brake-signal, are shown

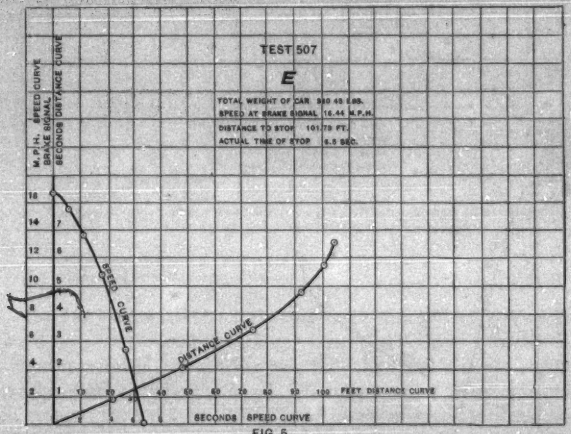

FIG. 5

graphically for the brakes under consideration, as this is the first question usually asked concerning the performance of a brake. A curve-sheet was worked up for each braking test, and specimens of these sheets for individual stops are shown in Figs. 1 to 6. A considerable number of individual sheets were worked up for each type of brake tested, and from these sheets were determined co-efficients or equations of curves of comparison, as shown on chart, Fig. 8.

Figs. 1 to 6 are specimen speed—time and distance—time curves for emergency stops with six different types of brakes. Fig. 7 is a diagram showing the method of obtaining accurate measurements of the distance required for stops. Fig. 8 is a

comparison chart showing stops from speeds of 12 to 18 m.p.h., with 6 different brakes. In Fig. 9 the recording apparatus used in these tests is illustrated, the means shown for producing a simultaneous record of current and voltage not being required for use in these brake-tests.

The following method was adopted to secure the requisite data for plotting these curves:

In all tests the same type of car was used, mounted on similar trucks, and all cars were put in as nearly the same condition as possible and loaded to the same gross weight by an amount equivalent to a heavy passenger load. The cars were run in the same direction over the same section of track on a uniform grade, wind

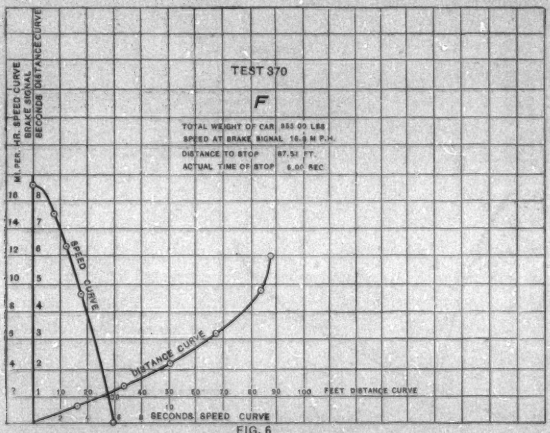

FIG. 6

and humidity conditions being as nearly uniform as possible, and great care was taken to determine with accuracy in each case the speed of the car at brake-signal and the actual distance traversed between brake-signal and the stopping of the car. An axle of the car was fitted with a drum carrying a contact plate which momentarily closed a battery circuit once in each revolution; this circuit energized an electromagnet operating one of two recording pencils, under which a strip of paper was drawn at uniform speed by a very accurately adjusted spring-motor. The operating magnet of the other pencil of the two above mentioned was energized by a circuit which was closed every half second by a contact maker actuated by a carefully adjusted clock-movement. It will

be readily seen that with this apparatus a record-sheet could be obtained that would contain a clear record of wheel-revolutions; from this the number of revolutions during any interval or the duration of any particular wheel-revolution could be determined with great accuracy; the method of using this apparatus to obtain the data desired was as follows:

DIAGRAM SHOWING METHOD OF DETERMINING DISTANCE FROM BRAKE-SIGNAL TO STOP.

When the arrow mark (↑) on wheel is in contact with rail, the revolution-counter circuit is closed by contact on axle. Each run started with this mark in contact. At stop the point of contact between wheel and rail was marked on rail, and the car rolled on until the arrow mark on wheel again came in contact with rail, giving the final fractional part of a revolution to be used in getting the total length of run by wheel-revolutions, which was subtracted from the length of run by tape measurement to get the distance skidded.

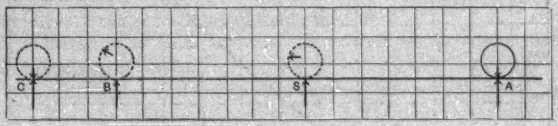

FIG. 7

A—Position of wheel at start.
B—Position of wheel at stop.
C—Position to which wheel was rolled to get last fractional part of a revolution.
S—Point at which brake-signal was given, determined by record of revolution-counter.
A B—Tape measurement; total distance run.
A S—Computed from Revolution-Recorder.
A B—A S = Distance to stop = S B.

The car was placed near the starting point and moved backward or forward until the contact on the axle drum was closed, then the point of contact between the wheel and rail was chalk-marked both on wheel and rail. Then the record-paper was put in motion, the car started and brought up to speed very gradually to avoid the possibility of slipping of the wheels. When the desired speed was attained, an electric bell was rung as a signal for an emergency stop. The circuit of this bell traversed the operating magnet of the chronograph pencil, and by drawing this pencil farther than it was ordinarily drawn by the clock circuit, produced a clearly defined record of the exact time at which the signal-bell was rung. When the car was brought to a full stop, the bell was rung again in order to make a record of the time elapsed between brake-signal and stop. The position of the point of contact of the front wheel was then carefully marked on the track and the car moved slowly along until the first chalk mark made on the wheel was brought again in contact with the rail, and the rail was marked at this point. A tape measurement

was then made between the first and second marks, giving accurately the total length of run; and between the second and third marks, to determine the distance traversed in the final fractional part of a wheel-revolution. The distance from start to brake-signal determined by the wheel-revolution record on the chronograph-chart was calculated; this distance deducted from the total length of run (a tape measurement), gave an accurate measure

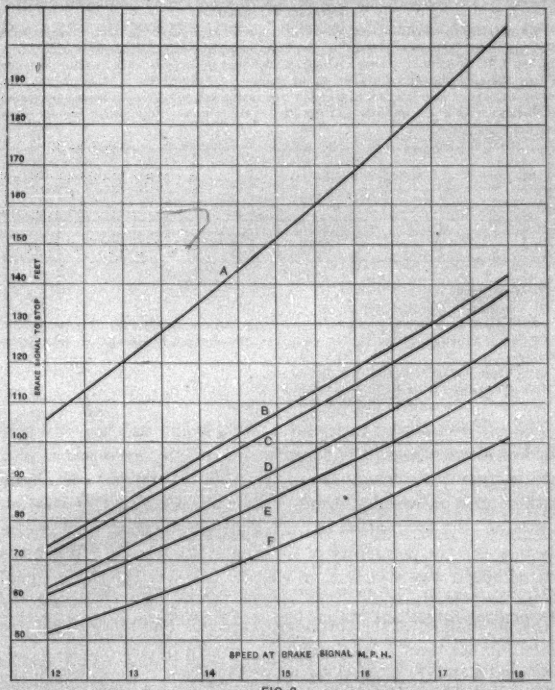

FIG. 8

of the distance from brake-signal to stop. Furthermore, where there was a difference between the total distance run by tape measurement and the total distance indicated by the wheel-revolution chart, such difference only occurred in case of skidding, then the difference was the measure of the distance skidded.

It should be noted that by the use of the methods outlined, the measurement of the two quantities whose accurate determination

is essential to an accurate brake-test—namely, the speed at brake-signal and the distance to stop—are obtained with a high degree of accuracy and with apparatus which can be attached to any car in a few minutes. This apparatus is complete in itself, no stops, signals or other special appliances being required on the track or roadbed.

The time elapsing between brake-signal and stop, may for the present purpose of tests of emergency stops be divided into three parts:

1. Duration of time between brake-signal and beginning of movement of brake-handle or lever by motorman; that is, the personal equation of motorman.

2. Duration of time between beginning of movement of brake-handle or lever and setting of the brake shoes.

3. Duration of time between the setting of the brake-shoes and stopping of the car.

The first interval of time above depends on the motorman, the second on the brake-mechanism, and the third on the amount of the frictional resistance which can be developed between the car and the rails, for a stop from a given speed. The first and second intervals of time are practically constant for a given motorman and brake-apparatus and independent of speed; the third interval will vary with the speed at brake-signal.

After being brought up to speed and allowed to run without power, the speed of cars on the test-track was found to fall off at the rate of about 0.16 miles per hour per second. Hence, for a given brake and motorman the distance run by car from time of brake-signal to time of full application of brake-shoe would be:

$$\left(S - \frac{0.16\,T}{2}\right) 1.467\,T = d \text{ (distance in feet)}$$

where S = speed at brake-signal in miles per hour,

T = time from brake-signal to application of brake-shoes.

At the end of time T the car would have run a distance d and would have a speed of $(S - 0.16\,T)$ miles per hour, and from this point to the point of stop, the distance d' would be:

$$\frac{(S - 0.16\,T)\,1.467}{2} \times \frac{S - 0.16\,T}{R} = d'$$

or

$$(S - 0.16\,T)^2\,\frac{1.467}{2\,R} = d'$$

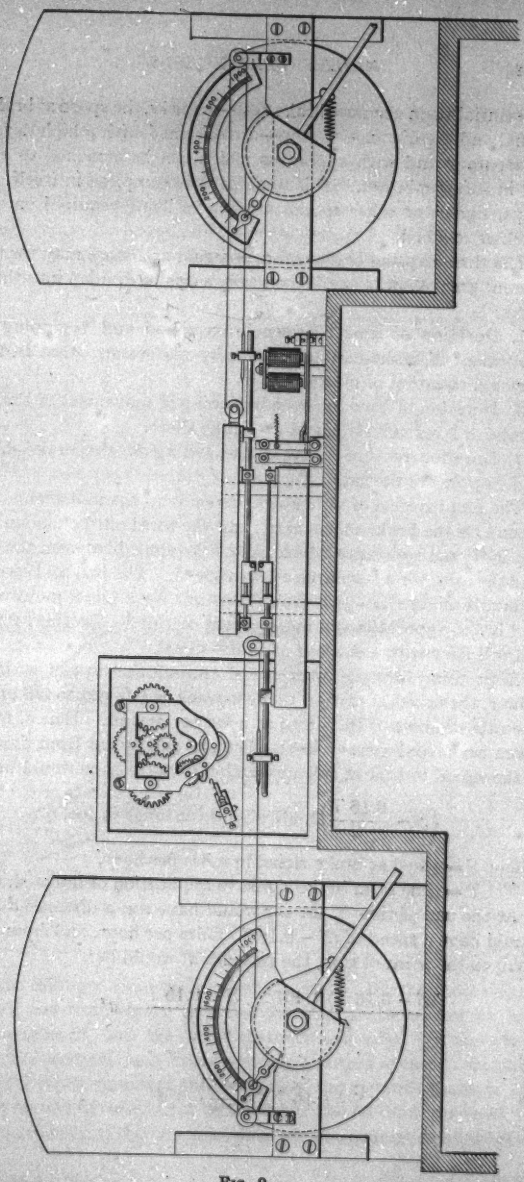

FIG. 9.

where R = rate of braking in miles per hour per second from setting of brake-shoes to stop.

The total distance being the sum of $d + d'$, we may write

$$\left(S - \frac{0.16\,T}{2}\right) 1.467\,T + (S - 0.16\,T)^2 \frac{1.467}{2\,R} = D$$

where D = total distance from brake-signal to stop. Collating the coefficients of S and S^2, we get the following equation, showing the relation between D and S:

$$D = L\,S^2 + M\,S + N$$

$$\text{where } L = \frac{0.733}{R}$$

$$M = \left(1.467 - \frac{0.235}{R}\right) T$$

$$N = \left(\frac{0.0188}{R} - 0.117\right) T^2$$

L, M and N being practically constant for each equipment.

From test stops, with each brake, curves were plotted showing speed on a time-base from the brake-signal to time of stop. From these curves may be obtained values for T and R, and from these the values of the coefficients of S^2 and S in the above equation may be computed. From this equation with D and S as variables, we may compute the values of D (distance) corresponding to several values of S (speed), and plot a curve showing for different speeds the distances run from brake-signal to stop for each of the equipments tested.

To get the time elapsed from brake-signal to stop from different speeds at brake-signal, we have the following relations:

T = 1st and 2d parts of time above referred to.

$\frac{S - 0.16\,T}{R}$ = 3d part.

Hence, the total time from brake-signal to stop from a given speed at brake-signal will be:

$$t = T + \frac{S - 0.16\,T}{R}$$

where t = time in seconds from brake-signal to stop.
T = time from brake-signal to setting of shoe.
S = speed at brake-signal.
R = rate of braking in miles per hour per second from setting of shoes to stop.

The coefficients of this equation for any equipment may be obtained as noted above from the speed-curves, and, these coefficients once determined, the values of t for several values of S may be computed; and from these values a curve may be plotted showing for different speeds at brake-signal the time from brake-signal to stop for each of the equipments tested. Distance- and time-curves have been plotted in this way for brakes A, B, C, D, E and F.

These charts show the relative efficiencies of the various brakes

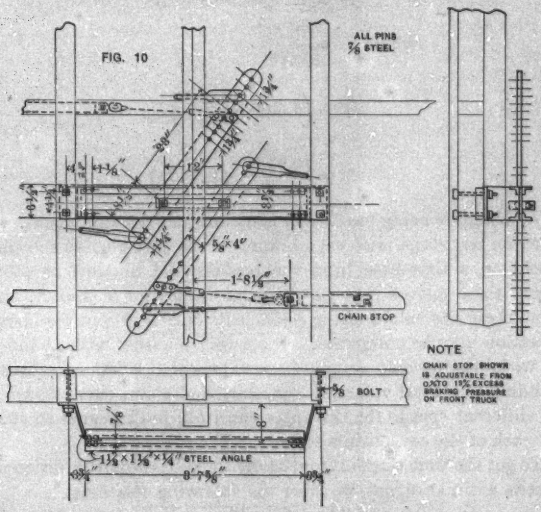
FIG. 10
ALL PINS 7/8 STEEL
CHAIN STOP
NOTE
CHAIN STOP SHOWN IS ADJUSTABLE FROM 0 TO 15% EXCESS BRAKING PRESSURE ON FRONT TRUCK
7/8 BOLT
1 1/2 × 1 1/8 × 1/4 STEEL ANGLE

FIG. 10.

for emergency stops; for instance, at 15¾ miles per hour speed at brake-signal, the distance from brake-signal to stop are:

For Brake	A, hand-brake,	164 ft.
" "	B, power "	115 "
" "	C, " "	112 "
" "	D, " "	100 "
" "	E, power-brake B, with differential levers,	93 "
" "	F, power-brake,	80 "

These curves show plainly the relative efficiencies of the several brakes in making emergency stops.

To reduce the liability to accident and to effect economy in the

use of motive power, it is desirable to secure as high a rate of braking as is consistent with the comfort of passengers; and if we assign a total cost per equipment per year to each type of brake considered, then the most desirable brake will be that for which this total is a minimum. The total cost per equipment per year should include the following items:

Cost of maintenance, labor and material.

Cost of power for operating brakes.

Interest on investment.

Cost of accidents per equipment per year.

The cost of maintenance and for power must be estimated from the best data at hand. As to the cost of accidents, a figure was readily obtained for hand-brakes. A figure was also obtained for brake D, for which the record of a number of equipments was accessible. From these amounts, chargeable to hand-brakes and brake D, the amounts which should be applied to the other brakes were estimated by a graphical method, taking into consideration the distances in which stops may be made with the respective brakes. Under the item of cost of power in the original comparison a charge was made against the hand-brake, which represents the amount of power necessary for operation with hand-brakes in excess of what would be required with a power-brake, due to the lower rate of braking with hand-brakes; as the same schedule speed can be maintained at a smaller expenditure of energy by using a more effective brake, the time of running with power being reduced and cars allowed to coast a greater distance.

Below is given an approximate comparison table for several power-brakes:

APPROXIMATE COMPARISON TABLE.

	A	B	C	D	E	F
Maintenance of power-brakes and extraordinary repairs, chargeable to brakes		58.80	10.95	36.25		29.20
Power		29.20			25.00	
Interest		15.00	5.00	6.50	17.50	11.50
Accidents		58.00	53.00	37.00	30.00	15.00
		161.00	68.95	79.75	72.50	55.70

The totals above, which are, of course, only of approximate accuracy, show that under certain conditions a very considerable

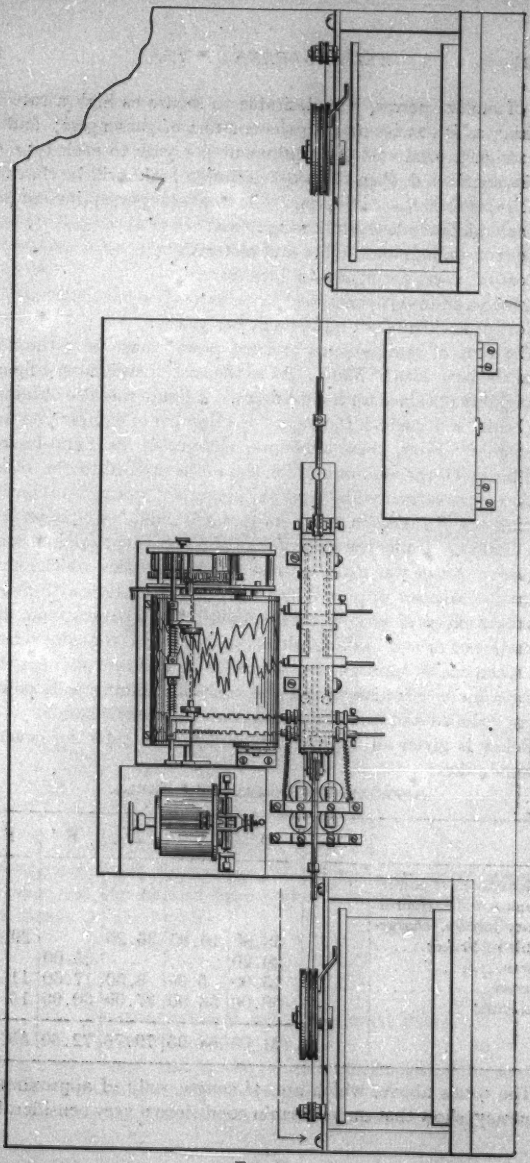

FIG. 11.

amount per annum may be saved by the judicious selection of brakes.

One practical result of the tests above described was the application by the writer of differential levers to hand-brakes; one form of construction of this type of foundation rigging being shown at Fig. 10. The levers as shown may be varied from 0 per cent. to 19 per cent. excess pressure on the front truck and may be adjusted to suit different types of car-bodies. Another result was the application of differential levers to one type of power-brake, the braking characteristic curves B and E, Fig. 8, showing that the distance required to stop a car with power-brake B has been reduced by approximately 18 per cent. by the use of non-equalizing levers, applying to the front truck a braking pressure exceeding that applied to the rear truck in a certain predetermined ratio.

A paper read at the 171st Meeting of the American Institute of Electrical Engineers, New York, Dec. 19, 1902.

RAILROAD-CAR BRAKING.

BY R. A. PARKE.

A sketch of the practical development of brakes in railroad service; an analysis of the results of investigation of brake-shoe friction; a definition of the requirements and limitations of brake efficiency in practice; a consideration of the loss of braking efficiency through disturbance of the normal rail-pressures by brake retardation and a description of the means of compensating for it. The peculiar characteristics of the magnetic brake are also briefly described. Illustrated.

The braking problem is as old as railroading and, in the early conception of it, the problem appeared a simple one. Practical railroading had no sooner accomplished the motion of trains than the necessity for stopping them appeared, and it was early perceived that the "adhesion," as it was usually called, or the frictional resistance to sliding of the wheels upon the rails, through which the wheels continue to rotate in spite of considerable resistance, is the most available retarding force. The application of a brake to the wheel to excite the retarding influence of the rail friction as naturally suggested itself, and when, in addition, the simple mechanism was provided for manually applying the brake to the wheel with sufficient force, in an emergency, to cause the wheel to slide upon the rail, the braking problem appeared to have been satisfactorily solved. Under the operating conditions of railroading then existing, the application by hand of brakes to a portion of the wheels of a train was ordinarily sufficient for all practical purposes, and when, in an emergency, the brake resistance so acquired was sufficient to overcome the

rail friction and cause the wheels to slide upon the rails, it was quite generally conceded that the most that could be expected had been accomplished and a disaster not averted by such means was accepted as one of the unfortunate but unavoidable contingencies of railroading. This early method of controlling the speed of trains has since been modified only by the substitution of mechanical for physical power in the application of the brakes, which has been extended to all the wheels, and by so restricting the pressure of the brake shoes that the wheels shall *not* be caused to slide upon the rails; but the diversified and intricate character of the influences now recognized as constituent elements in the efficiency of the power-brake, have involved the subject in much complication.

The advantage of the use of power, under the control of the engineef, for promptly applying brakes upon all the wheels of a train, early became recognized, and the special advantages of compressed air for the transmission of the power throughout trains of considerable length, established the air-brake in a pre-eminent position. At first, the compressed air was stored in a reservoir upon the locomotive and, by means of a line of iron pipe, extending throughout the length of the train, with flexible hose and couplings between vehicles and an operating valve upon the locomotive, it was conducted to the brake-cylinder upon each car, by which the brakes were applied to the wheels, through the intervention of suitable rods and levers. The time required to convey the necessary volume of compressed air from the storage reservoir upon the locomotive to all the brake-cylinders of even a comparatively short train, and the total disability resulting from rupture at any point of the air-conduit, caused this form of air-brake to be supplanted by the automatic air-brake, in which an auxiliary storage reservoir, of sufficient capacity to operate a single brake-cylinder, was added upon each car. Through the operation of a triple-valve device, which connects the train-pipe or air-conduit, the auxiliary reservoir and the brake-cylinder upon each car, admission of compressed air into the train-pipe causes each auxiliary reservoir to become charged to operate the brakes, and discharge of air from the train-pipe, from any cause, causes communication with the auxiliary reservoir to be transferred from the train-pipe to the brake-cylinder, whereby a corresponding quantity of compressed air is discharged from the auxiliary reservoir into the brake-cylinder. By defining the reduction of pressure of air in the train-pipe, the pressure of the brake-shoes

upon the wheels may be graduated to any desired degree within the limit established by the ultimate equalization of air-pressure in the auxiliary reservoir and the brake-cylinder, and accidental rupture of the train-pipe instantly operates to stop the train and to prevent further progress without effective repair. In any case, restoration of the air-pressure in the train-pipe actuates the triple valve to re-establish access to the auxiliary reservoir, whereby it is recharged with air-pressure, and to transfer communication with the brake-cylinder from the auxiliary reservoir to the atmosphere, through which the brakes are released.

When the automatic air-brake became employed upon freight-trains, it was discovered that, in making a quick stop by venting the train-pipe at the locomotive, the interval of time required to cause an operative reduction of the air-pressure in the train-pipe at the rear end of the train was so considerable that effective application of the brakes upon the rear cars was delayed until sufficient retardation of the forward portion of the train had become effected to cause collision with the rear cars that damaged and often disabled the cars and did violence to the lading. To remove this obstacle, the automatic air-brake became superseded by the quick-action automatic air-brake, in which, when a quick stop is desired, each triple-valve opens a vent in the train-pipe, in addition to the vent upon the locomotive. By this means, an operative reduction of the air-pressure progresses throughout the train-pipe, of the longest trains, with nearly the velocity of sound, and damage from the serial character of the application of brakes by compressed air becomes practically eliminated. Incidentally, also, in the local venting of the train pipe air at each succeeding triple-valve, the utilization of this source of power, formerly wasted at the engineer's operating valve, was accomplished by conducting the vented air into the adjacent empty brake-cylinder, before it receives the ordinary supply provided by the auxiliary reservoir. Thereby, the ultimate air-pressure in the brake-cylinder is augmented about 20 per cent., and the character of the application of the brakes in disaster-threatening emergencies is further distinguished from that in ordinary service, where neither the violence nor the power of the emergency application is desirable or even tolerable.

While the character of the development of the compressed air brake has thus been chiefly dictated by conditions rendered conspicuous by increased length of trains, and would hardly have been suggested under the conditions to which electric railroad

operation appears best adapted, the high operative efficiency and other advantages thereby acquired are participated in by short as well as long trains, and are therefore of interest in dealing with the question of braking in electric service. Where even only two cars are operated together as a train, the automatic feature of the air-brake is still essential, in precisely the same way, if not in the same degree, as in longer trains, and, except where cars are always operated singly, the same is true of the increased efficiency secured through the quick-action feature of the automatic brake.

The first systematic or comprehensive investigation of the effect of brakes upon the wheels of moving vehicles was that of an elaborate series of experiments, conducted upon the London, Brighton and South Coast Railway, in 1878, with apparatus constructed and operated by George Westinghouse, under the supervision of Capt. Douglas Galton, representing the Institution of Mechanical Engineers, and which are now commonly known as the "Westinghouse-Galton" brake-tests. The ingenuity and perfection of the apparatus, and the scientific and unbiased character of the experiments, establish this investigation upon a high scientific plane and give its results an authoritative standing which has never been impaired or supplanted by subsequent investigations. Had the range of these experiments been extended but a little farther, the entire subject would have been elucidated. In fact, while later experiments have demonstrated the importance of additional information, that information has not yet been definitely supplied, and the Westinghouse-Galton investigation still stands as the only reliable source of definite knowledge concerning the important characteristics of brake-shoe friction.

More recent investigations have been conducted upon a machine devised for experimenting upon the friction of brake-shoes, but their purpose has been to determine the relative commercial values of brake-shoes of different materials, rather than to supplement the information furnished by the Westinghouse-Galton tests. While such investigations have doubtless been useful in indicating the relative advantage of different materials for brake-shoes, and have perhaps satisfactorily determined, within limits, the degree of efficiency which may properly be required of brake-shoes, they have added to previous knowledge of brake-shoe friction only in suggesting certain general characteristics, without furnishing adequate data to extend our knowledge of the action of brakes in stopping a train.

The Westinghouse-Galton experiments were conducted in a

moving four-wheeled car, provided with the necessary recording apparatus, the wheels being steel-tired and the brake-shoes of cast iron, and the results of the experiments may be summarized as follows: The coefficient of brake-shoe friction decreases with increased speeds and, at constant speed, it decreases with the increase of the time that the surfaces are in contact. The coefficient of friction does not appear to increase with increased pressure per square inch. When the wheels roll without sliding upon the rails, the rail-friction (or adhesion) is unaffected by the speed, but declines greatly with sliding of the wheels, when it varies inversely with the speed, corresponding with the brake-shoe friciton, but is much inferior thereto. The rail-friction is very materially affected by the condition of the rail, being greatest when the rail is perfectly dry or very wet (as when washed by a hard rain) and least when the rail is quite moist; but, by the use of sand upon the rails, the effect of moisture is practically eliminated.

The actual variation of the brake-shoe friction with increased speeds is very regular, beginning with the friction of rest (static friction) and declining, very rapidly at first, but with continually decreasing rapidity, up to the highest speeds of the experiments. The undoubted fact that the friction cannot vanish for any finite speed, considered in conjunction with the peculiar character of the decline, suggested to the writer that the results of the experiments might be properly represented by a portion of an equilateral hyperbola, and upon applying the theory of probability to the mean results, the coefficient of friction is found to be represented by the equation

$$f = \frac{.326}{1 + .03532\,V}$$

in which V represents the speed in miles per hour. The following table shows both the computed coefficients of friction from this formula and the means of the observations, up to a speed of 100 miles an hour.

Speed V.	Coefficient of friction, f.		Speed V.	Coefficient of friction, f.	
	Computed.	Observed.		Computed.	Observed.
0	.326	.330	45	.126	.127
5	.277	.273	50	.118	.116
10	.241	.242	55	.111	.111
15	.213	.223	60	.105	.074
20	.191	.192	65	.099	
25	.173	.166	70	.094	
30	.158	.164	80	.085	
35	.146	.142	90	.078	
40	.135	.140	100	.072	

It is worthy of note that the mean observed result for a speed of 60 miles per hour differs materially from the result of a law that applies with remarkable fidelity to the observed results at other speeds. This is perhaps attributable to two causes: first, while each of the other results (except for the lowest three speeds) is the mean of from 54 to 90 experiments, that for 60 miles represents but twelve experiments—much the smallest number at any speed—of which, the maximum observed result was .123 and the minimum was .058. The other probable cause is that, it having been discovered that the coefficient of friction is less at high speeds, the pressure was much increased at the very high speeds to compensate, and it is now known that the coefficient of friction is an inverse function of the pressure. The mean result at 60 miles an hour does not, therefore, appear to be fairly comparable with those at other speeds, and it has been rejected in determining the constants in the above formula.

In the tabulated results of these experiments, Capt. Galton gives the maximum and minimum, as well as the mean value of the coefficient of friction observed for each speed. It is observable that the maximum values very well follow a similar law to that above given for the means, while the minimum values are too irregular to suggest more than a general inclination to decline as the speed is increased. As the maximum values correspond more nearly with the results of more recent experiments, the writer has also formulated them. The most probable law is represented by the equation

$$f = \frac{.382}{1 + .02933\,V}$$

and the calculated and observed values are given in the following table:

Speed V.	Coefficient of friction, f.		Speed V.	Coefficient of friction, f	
	Calculated.	Observed.		Calculated.	Observed.
0	.383		45	.165	.179
5	.333	.340	50	.155	.153
10	.295	.281	55	.146	.136
15	.265	.280	60	.138	.123
20	.241	.240	65	.131	
25	.220	.205	70	.125	
30	.203	.196	80	.114	
35	.188	.197	90	.106	
40	.176	.194	100	.097	

The decrease of the coefficient of brake-shoe friction from continued contact apparently follows the same character of law as does that from increase of speed; that is, the fall is rapid at first,

but the rate of fall quickly begins to decline. It was assumed by Capt. Galton that the decline of the friction is as the increase of the time of contact, but a careful analysis of the results shows that it is a function of the product of the speed and the time, or of the distance through which the shoe rubs upon the wheel. It is very unfortunate that the observed effect of continued rubbing does not extend over sufficient time to permit reliable formulation. The more recent experiments appear to show that, at the same speed, the friction becomes constant after a time, but it is probable that the coefficient of friction continues to yield to the influence of continued rubbing throughout stops from the highest speeds yet attained in practice. In formulating the incomplete data of Capt. Galton, therefore, the purpose is merely to present as comprehensive a view as possible of the complexity of the subject, and the results must not be accepted as trustworthy for practical use. Accepting the conclusion drawn from later experiments, that the coefficient of friction remains stationary after some definite period of continued rubbing at constant speeds, the question is still open as to whether the stationary point is the same for all speeds or is simply a function of the initial coefficient of friction, corresponding to the speed and brake-shoe pressure. While there is no definite information upon this point, beyond the limited observation of the Westinghouse-Galton experiments, that, so far as it goes, points to the latter view, and all our information suggests the probability that the ultimate level is different for each different initial coefficient of friction. The corresponding equilateral hyperbola is therefore represented by an equation of the form

$$f_1 = \frac{1+hs}{1+cs} f$$

where f is, as hitherto, the initial coefficient of friction, corresponding to the speed and pressure, s is the distance, in feet, through which the surface of the wheel has travelled in frictional contact with the brake-shoe, and h and c are constants. Applying the theory of the least squares to the observations of Capt. Galton (except those at a speed of 60 miles an hour, which are rejected for reasons already given), the values found for h and c cause the above expression to become

$$f_1 = \frac{1+.000472\,s}{1+.002390\,s} f$$

Thus the coefficient of friction, f, for a given speed, as indicated

in the tables already submitted, becomes reduced, after the brakes have been applied through a distance of 50 feet, to .914 f; after 100 feet, to .845 f; after 200 feet, to .740 f; after 300 feet, to .665 f; after 500 feet, to .563 f; after 1000 feet to .434 f; after 2000 feet, to .336 f; and the ultimate level, which is not yet reached after two miles, is 472/2390 f, or about .2 f. The later experiments upon the efficiency of brake-shoes included some temperature tests, the results of which indicate that, under the conditions of those experiments, the stationary level is reached after from 2000 to 3000 feet, and there is good reason to believe that it is much higher than .2 f. Of the observations employed in determining the constants in the above expression, none was for a greater distance than 814 feet and the larger number were for short distances, which thus gave undue weight to the rapidly falling feature of the curve. In the absence of more extended observation, no practically useful mathematical application of this characteristic of brake-shoe friction can be realized. As it exerts a very important and effective influence upon the friction and the rate of retardation during every stop, the impossibility at present of determining the rate of retardation under varying conditions is obvious. Grade, for instance, not only affects the rate of retardation by directly modifying the effective retarding force, but also, in varying the distance in which a given reduction of speed occurs, it again indirectly affects the rate of retardation. It thus happens that experimental determinations of the rate of retardation are more misleading than useful under any other conditions than exactly those of the experiments. Experimental stops of the same train, made one right after another, from the same speed, at the same place, on the same track, differ very materially from obscure causes of this character, while the conditions apparently differ so little that they are looked upon as "practically" the same. The errors, accidents and other sins that occasionally result from the prevailing custom, in this practical, money-getting age, of founding conclusions upon premises that are "good enough for practical purposes," have no better illustration perhaps than in the matter of train stops, in which the enjoyment of confidence in one's conclusions generally varies inversely with accuracy of understanding of the subject.

In order to observe the effect of varied pressure in the Westinghouse-Galton experiments, a set of brake-shoes was made with projections cast upon their face, so that only about one-third the whole surface of the shoe came into contact with the wheels.

What actual pressure was then applied to the wheel is not recorded. From statements of Rennie, concerning the results of experiments upon the relation of pressure to static friction, it was expected that the coefficient of brake-shoe friction would be considerably increased by the increased pressure per square inch resulting from this modification of the brake shoes; but Capt. Galton says of these experiments simply that he is not prepared to say that any greater coefficient of friction was obtained, and that but a very small number of experiments were made with these special brake-shoes because the projections were entirely worn off in twelve applications. In view of the division of the rubbing surface into a considerable number of small surfaces with edges more or less sharp, it is doubtful if any reliable conclusions could have been drawn from pressure experiments in which the variation of the pressure per square inch is secured by such means. More recent experiments have shown very conclusively that, other conditions being the same, the coefficient of friction declines as the pressure increases and, while insufficient data has yet been presented to determine the character of the decline, there are substantial reasons for believing that it follows the same character of law as do the declines from increased speed and extended rubbing contact.

This view of the dependence of the coefficient of friction upon pressure, throws some light upon the considerable range of observed values recorded, at the various speeds, in the experiments to determine the influence of speed upon the coefficient of friction. In some cases, the brake-shoe pressure employed was more than three times the weight upon the rails, while at other times the pressure was but about one half that weight, so that the pressure varied from about 40 to about 250 pounds per square inch of brake-shoe surface. It is most significant, also, that in the cases cited in Capt. Galton's reports to illustrate special conditions, high pressures are accompanied by coefficients of friction that are about the minimum observed for the corresponding speeds, while the lowest pressures are accompanied by the maximum coefficients. As it is to be assumed, of course, that the coefficients of friction given in the tables for different speeds are those observed at the beginning of application only, it appears most probable that the quite uniformly large range of values for the different speeds is principally due to variation of pressure. Under such conditions, therefore, it can only be assumed that the table of mean coefficients of friction for different

speeds is representative also of the mean brake-shoe pressure during the experiments, which is probably about 90 pounds per square inch, though it cannot be definitely determined from the data given in Capt. Galton's reports, while the table of maximum coefficients appears to represent a pressure of from 40 to 50 pounds per square inch, or a total pressure of about 2000 pounds upon the standard brake-shoe in this country.

The coefficient of rail-friction was found to vary for dry rails from .19 to .35, and averaged about .25. Upon wet or greasy rails, without sand, it fell to as low as .15 in one experiment, but averaged .18. With sand upon wet rails, it never fell below .20 and rose in some cases as high as to .40, so that, with the use of sand, the rail-friction of a wet rail is at least equal to that of a dry rail without sand. When the brake-shoe friction overcame the rail-friction, and caused the wheels to slide upon the rails, the coefficient of rail-friction immediately began to decline and then varied inversely as the speed, in much the same way as brake-shoe friction, but is much inferior thereto. This may be readily explained by the greatly reduced area of contact and consequent high pressure per square inch between wheels and rails. It may also, of course, be due in some measure to inferior frictional qualities of the steel wheel upon steel rails, as compared with cast-iron brake-shoes upon steel wheels.

The maximum retardation which may be utilized in stopping railroad vehicles by the customary means of brakes is therefore that which is realized by so applying brake-shoes to the wheels that the resulting brake-shoe friction shall be uniform, and just insufficient to overcome the constant, static rail-friction. If sand be suitably provided whenever the condition of the rail requires it, the coefficient of rail-friction always available (unless perhaps in the case of railroads running in streets) is at least .20 and may doubtless be safely regarded, in at least all cases where emergency calls for the highest efficiency, as .25 of the pressure of the wheel upon the rail. A brake system of ideal efficiency in the time of necessity is thus one in which the brake-shoes are so applied to the wheels that a retarding rail friction equal to one-fourth the weight of the train is instantly realized and continuously maintained throughout the stop. In such a case, the retardation (ignoring the resistances of rolling friction and the atmosphere) is one-fourth the acceleration of gravity, or 8.04 feet per second. which amounts to reducing the speed at the rate of almost 5½ miles an hour per second. Stops would be made in a distance

represented by .1338 V^2, where V is the initial speed in miles per hour, or in 482 feet at 60 miles an hour, 214 feet at 40 miles an hour and only 53½ feet at 20 miles an hour. The obstacles to the realization of a brake of such efficiency are apparent at once when the variable nature of the coefficient of brake-shoe friction is understood, and the difficulties which attend variation of the pressure of the brake-shoe upon the wheel to compensate for the fluctuation of the coefficient of friction through the simultaneous operation of such complex influences, appear insuperable. But the problem is not entirely hopeless and it is useful to consider what has been and what may yet be done to increase the efficiency of braking.

In the outset, while at first glance the coefficient of static rail-friction, which measures the maximum retardation, appears to be inflexibly established, such is not altogether the case. The inferiority of the coefficient of friction between the wheel and the rail to that of the brake shoe upon the wheel must be attrjbuted chiefly to the very great difference in the areas of the surfaces in contact and the consequent difference in the pressure per unit area. The convenient doctrine of Morin, that the friction is independent of the area of the surfaces in contact, has been the cause of much misapprehension and of many errors of construction. Mr. P. H. Dudley has clearly demonstrated that broad-headed rails yield a materially greater tractive power to locomotives than narrow-headed ones, and it may be confidently assumed that any means of increasing the surface of contact between wheels and rails adds to the resistance which measures the maximum efficiency of the brakes. The theoretical *line* of contact between a wheel and a rail broadens out practically into a somewhat pear-shaped surface, which differs in form and extent with different materials and pressures. The head of the rail is locally depressed and the circular periphery of the wheel becomes flattened, resulting in a surface of contact, the extent of which depends upon the elasticity of the materials, the diameter of the wheel and the forms of the rail-head and wheel-tread. It is evident that a greater contact area occurs with a large than with a small diameter of wheel, and it is equally clear that greater elasticity of the material of either wheel or rail conduces to the same result. Steel is generally more elastic than chilled cast iron, and recent observation indicates a higher coefficient of rail friction with steel-tired wheels than with chilled iron. It is true that, while such a result should be expected because of a larger area of

contact, it may also be that the frictional qualities of the materials in contact constitute a factor of some importance. It has generally been understood that the dynamic friction of cast-iron brake-shoes upon chilled cast-iron wheels, exceeds that of the same shoes upon steel-tired wheels. While this conclusion does not appear to have been actually established, yet, even if it be correct, it does not follow that the static friction of steel-tired wheels upon *steel rails* may not be greater than that of chilled cast-iron wheels. But, whatever the fact may be in this respect, it is reasonable to expect that the most effective *surface of rail-contact* occurs with large, steel-tired, straight-tread wheels upon broad rails, and, so far as our information yet extends, observation confirms this view sufficiently to warrant the statement that it is a matter of considerable importance.

The utilization of the retarding force available as rail-friction, by means of brakes, involves the application of a brake-shoe pressure which shall (*a*) diminish as declining speed causes the coefficient of friction to increase, which shall (*b*) increase as increased distance of frictional contact causes the coefficient of friction to decline, and which shall (*c*), when diminishing or increasing for such purposes, further diminish or increase as reduction or increase of pressure itself causes the coefficient of friction correspondingly to increase or decline. The combined effect of declining speed and increasing distance is far from being uniform in stops from different initial speeds. The friction apparently declines from continued rubbing in about the same proportion, through a given distance—the first 100 feet of the application, for illustration—whether the initial speed is high or low; but the elevation of the coefficient of friction by declining speed during such first 100 feet of application, is much less proportionally when the initial speed is high than when it is low. The two opposing influences are thus not uniformly effective. In stops from low speeds, the coefficient of friction increases, slowly at first and rapidly at the close, but continuously from beginning to end. At high speeds, the elevating influence is proportionately less effective at first, so that, for a time, the friction remains about stationary, or even declines at first before becoming stationary; but it always subsequently rises with an increasing rapidity that becomes so great as to be almost abrupt at its termination. It is therefore a characteristic of all stops that the coefficient of friction is comparatively low during the early portion and much higher toward the close; and, while manipulation

of the pressure to compensate for the compound fluctuation of the coefficient of friction appears hopelessly complicated, a partial realization of the efficiency of such an ideal brake system may be accomplished by employing a comparatively high brake-shoe pressure during the early part of the stop and subsequently so reducing it that the high coefficient of friction near the end of the stop shall not cause the wheels to slide upon the rails. The provision of means by which this partial utilization of the advantage of compensating the pressure is practically realized constitutes the latest and highest progress thus far made in the practical development of the air-brake.

In accomplishing the purpose of applying an increased brake-shoe pressure during the early part of the stop, the quick-action automatic brake has been modified by the addition of an automatic pressure-reducing valve to each brake-cylinder, by the use of which a high air-pressure is utilized in the brake-cylinder in emergency applications of the brakes, and is gradually reduced to the level of that which, in earlier forms of the air-brake, is maintained continuously throughout the stop without sliding wheels at the close. That material progress in braking is marked by this step will be easily appreciated when it is understood that, with the use of this apparatus, called the " high-speed " brake, stops from the higher speeds are about 30 per cent. shorter than those attained by the quick-action brake. By the more prompt application of a greater brake-shoe pressure than immunity from injurious wheel sliding permitted in ordinary applications of the brakes, the " emergency stop " became clearly distinguished by the quick-action air-brake, and, in passenger train service, it was shortened to about 80 per cent. of the shortest stop of the older automatic air-brake. By the application of a greater brake-shoe pressure during the early period of stops, for utilizing a larger proportion of the retarding force realized at lower speeds, the high-speed brake shortens emergency stops from high speeds, to about 70 per cent. of those of the quick-action brake, or 56 per cent. of those of the old automatic brake. The increased brake-shoe pressure is secured by the use of a high air-pressure, which, through the operation of the automatic reducing valve, is available only in emergency applications of the brakes, the moderate pressures of the old automatic brake being still preserved in ordinary operation to prevent possible injury of wheels. But the higher storage-pressure of the auxiliary-reservoir air is equivalent to a correspondingly increased volume of air stored at the

pressure of ordinary service, and thus the high-speed brake also provides for repeated brake-applications without recharging the auxiliary reservoirs—an incidental advantage greatly increasing the security of trains under conditions of daily occurrence.

It is opportune to digress at this point to consider an application of the high-speed brake which concerns conditions to which electric railroad operation is peculiarly adapted. Hitherto, the ordinary stops of railroad trains have generally consisted of a preliminary reduction of speed at a long distance from the stopping point, to bring the train under full control, and then of a gradual reduction of the remaining speed, continuously or in stages, to suit the conditions or the operator's views, until the train comes to a standstill at the stopping point. The stops of express trains have been infrequent, and the speed of way trains has been moderate, so that, in both cases, the time occupied in the stop has not called for careful consideration. But with the rapid growth of suburban traffic in all large cities, particularly since the introduction of electric railroads, the changed operating conditions of suburban trains give great importance to the time consumed in the frequent stops. Both in steam and electric railroad traffic of this kind, large expenditures of thought and money have been made to secure high acceleration in starting trains, while almost nothing has been done to secure the equally important high retardation in stopping. Every start is accompanied by a stop, and if economy of time is important in one, it is equally important in the other. The neglect which efficiency of stopping has suffered is doubtless due to the fact that, while acceleration in starting has generally been limited to that which may be acquired from the rail-friction of a few wheels, the retardation resulting from brakes upon practically all the wheels is so effective in comparison that its inferiority to what it *might* be is overlooked. Moreover, the character of the train-stop of ordinary service has been so firmly established and avoidance of the use of the full power—the emergency application—of the brake has been insisted upon for such good reasons, that departure from the customary "service" application of the brakes does not readily suggest itself. But the conditions now under consideration are quite different. At low speeds, the violence of the emergency application is apt to result in discomfort to passengers, and the brake-shoe pressure is too near the wheel-sliding limit to be desirable. But at the high speeds attained between stations in efficient suburban service, the initial coefficient of brake-shoe

friction is so low that no perceptible shock or disagreeable effect accompanies an emergency application of even the high-speed brake; and the coefficient of friction near the end of the stop is so much lower, through the effect of continued rubbing through so much longer distance than in a stop from the lower speeds, that the danger of wheel sliding is not troublesome.

There is also another important time-saving feature of the emergency application for service stops in train service of this character. In making an ordinary service application, the personal equation of the operator is an important element. The proper point at which to apply the brake, the force of initial application and each subsequent increase or reduction of the braking force (to prevent over-running or stopping short of the station) are matters of personal judgment in which men differ materially; the consequence of which is that, to be safe, the brakes are usually applied too early and time is lost in drifting into the station at low speed. In an emergency application, the personal element is largely eliminated, as the full application is practically instantaneous and, where definite speed may always be depended upon, the point at which the brakes should be applied may be designated by a signal post. Thus, full speed might be obtained over much the larger part of the distance traversed during an ordinary service stop, followed by a quick stop of the high-speed brake, and fully half the time occupied by the service stop would be saved.

Thus far, consideration of means for approaching the theoretically possible retarding force has been confined to those for overcoming the obstacles due to the complicated variation of the coefficient of brake-shoe friction. This is a subject which, while of manifest interest and importance to those who operate railroads, chiefly concerns those who supply the motor mechanism for applying the pressure of the brake shoes upon the wheels. The distribution of pressure upon the rails, through the wheels, which defines the maximum rail friction itself, and the construction of running gear and brake-beam supports to permit the utilization of the rail-friction for retardation, constitute a branch of the subject which ought seriously to concern those who construct the running gear and apply the motive power, but which is almost invariably subordinated to every other consideration and is usually overlooked entirely. It is a strange fact that, although the brake occupies the uppermost position of importance among railroad safety appliances, the actual work of stopping trains when

disaster impends, depending entirely upon it—and almost as much depending upon it as upon the motive power apparatus for high efficiency in local and suburban train operation—every effort is apparently concentrated upon attaining the maximum acceleration in starting trains and the almost equally important matter of high retardation in stopping is so far neglected that efficient foundation brake-gear is not only usually not provided but often prohibited, and especially where electricity is the motive power. It is obvious that the force with which the brake-shoes should be applied to a pair of wheels depends primarily upon the pressure of those wheels upon the rails. In car construction, the weight is usually, but not always, equally distributed upon the various wheels. In electric car construction, it frequently occurs that the motors are so applied that greater weight is supported by one pair of wheels than by another. In any case where the wheel pressure materially differs, proper regard for brake-efficiency demands that the brake-shoe pressure shall correspondingly differ. But, entirely independent of the normal distribution of weight upon the various wheels of a vehicle, retardation itself, caused by the application of brakes to the wheels, involves a redistribution of the weight which, where the retardation corresponds to the maximum brake application, inevitably results in a very serious loss of braking efficiency, unless means be provided for varying the brake-shoe pressure to correspond with the changed wheel-pressures. Whatever the source of the retarding force, its operative effect in retarding the motion of the car is the same as that of an infinite number of small retarding forces, each engaged in retarding the motion of an elementary portion of the mass of the car, and therefore, in order that a single retarding force, or a combination of retarding forces, shall so operate, without either changing the direction of the car's motion, or producing rotation of the structure as a whole, or calling into operation other forces to prevent such deviation or rotation, the force or the resultant of the combination of forces must be so applied that it shall pass through the centre of inertia of the mass, in a direction opposite to that of the motion of the car. In utilizing the rail-friction for the retarding force, while it has the proper direction, it is applied at the lowest points of the mass of the car and must therefore either cause rotation of the entire structure or the interposition of other forces which combine with the retarding force to preserve the simple motion of translation. The car may be considered as a single mass or as being

composed of three separate masses, according as it is provided with one rigid or two swiveling trucks. Rotation of the car by the eccentric retarding force does not occur in either case; but, in the first, it is because the reacting pressure of the rails upon the forward pair of wheels exceeds that upon the rear pair of wheels in such measure that the contrary rotative moment, thereby introduced, just balances that of the eccentric retarding force, also applied by the rails to the wheels. In the case of the car with two trucks, the retarding force is applied at the lower extremity of the two trucks, being equally divided between them (if constructed alike); that portion of the retarding force necessary to retard the mass of the trucks is absorbed in so doing, and the remainder is applied by the trucks to the car body at substantially its lowest extremity. In consequence, the center of inertia of the car body being above the points of application of the retarding force, rotation through the eccentrically applied retarding force is prevented only by the resisting rotative moment of a greater supporting pressure from the forward than from the rear truck. Each truck is subject to the combined rotative moment of the eccentric retarding force at its lower extremity, and the eccentric reacting force from the car body at its upper extremity, and rotation is prevented only by the contrary rotative moment of a greater supporting pressure by the rails upon the forward than upon the rear pair of wheels. Thus the very act of applying the brakes to the wheels produces a new and very different system of wheel pressures upon the rails, and it is the wheel pressures under these conditions which determine the available retarding force. As the total pressure of all the wheels upon the rails cannot vary, it is obvious that the existence of a greater rail pressure for the forward than for the rear pair of wheels of the truck implies the virtual transfer of a portion of the normal pressure from one pair of wheels to the other. The brake-shoe pressure upon the rear pair of wheels must be insufficient to cause the wheels to slide upon the rails, and must therefore be cut down in proportion to the transfer of weight from the rear to the forward pair of wheels. But as the forward pair of wheels will become the rear pair when the car moves in the opposite direction, the brake-shoe pressure upon that pair of wheels must also be limited in the same way. Thus, the braking pressure upon each pair of wheels must be restricted to correspond with the minimum pressure of the wheels upon the rails, and when it is understood that this minimum rail-pressure, which

occurs in the maximum application of the brakes, is less than 85 per cent. of the normal, or, in other words, that the effective wheel-pressure, available for braking, of an ordinary eight-wheeled passenger car is but 85 per cent. of the weight of the entire car, the importance of the provision of means to compensate for such a serious loss of retarding efficiency becomes clearly manifest, and a solution of the problem, devised by the writer, is therefore submitted.

The first step in determining the rail-pressure is to find the reactions between the car-body and trucks, after which, investigation is confined to truck-conditions alone. The only means of the application of force to the car-body are the trucks and the draw-bars. In any case where, in a train of vehicles, the ratio of the retarding force of the brakes to the weight is greater for some vehicles than for others, the forces transmitted through the draw-bars require consideration; but in electric service, where cars are either operated singly or in trains that permit equally effective brake-retardation upon the several vehicles, no one produces a retarding effect upon another, so that draw-bar forces are eliminated and the problem is more simple than in the case of steam-railroad trains, where draw-bar forces accompany brake-application, because all vehicles are not uniformly braked. It is true that, in a train of electrically operated cars, defective apparatus upon one or more of the cars might result in the application of the brakes upon only a portion of the cars, whereby retarding forces would be transmitted through the draw-bars to the unbraked cars, but consideration can hardly be extended to such uncertain accidental conditions.

Fig. 1 represents the body of a car, from which the trucks have been removed and replaced by arrows representing the supporting and retarding forces which they apply to the car. The trucks being alike and subject to the same retarding rail-friction, each truck contributes the same horizontal force (H) to retard the mass of the car-body, and the forward truck applies a vertical supporting pressure P_1, while the rear truck similarly applies the supporting pressure P_2. The weight (W_1) of the car body is represented by an arrow acting downward through the center of inertia of the car, midway between the truck supports and at distance k above them. The distance between the truck supports is represented by l. These are all the real forces acting upon the car-body (in the absence of draw-bar forces), as the resistance of the atmosphere is so insignificant in comparison with the rail-friction that it may be neglected.

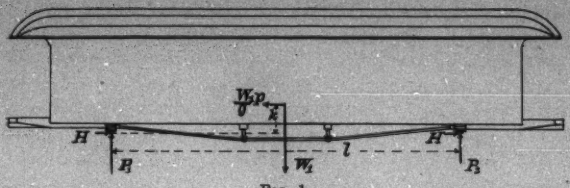

FIG. 1.

The rail-friction causes all parts of the car-structure to be retarded at a certain rate (p) and the horizontal forces (H) from the trucks are absorbed in overcoming the resistances of inertia of all the various elements of mass of the car-body, which latter thus constitute a system of imaginary forces that may be represented in the aggregate by an equivalent horizontal force, which is the product of the mass of the car-body (W/g, where g represents the acceleration of gravity) and the common retardation (p), acting at the center of gravity in a direction opposite to that of the retarding forces H. The operation of the real forces must thus be equal and opposite to that of the imaginary forces, and the following conditions are therefore evident:

$$P_1+P_2-W_1=0, \text{ or } P_1=W_1-P_2$$

$$2H=\frac{W_1 p}{g}, \text{ or } H=\frac{W_1 p}{2g}$$

$$W_1\frac{l}{2}-P_2 l=\frac{W_1 p}{g}k, \text{ or } P_2=\frac{W_1}{2}-\frac{W_1 p k}{g l}$$

Also, combining the first and last of these equations,

$$P_1=\frac{W_1}{2}+\frac{W_1 p}{g}\frac{k}{l}$$

By comparison of these values of P_1 and P_2, it is evident that, of the weight $W_1/2$, normally supported by each truck, the weight $p k W_1/g l$ has, through the application of the brakes, been removed from the rear truck and transferred to the forward truck. The center of gravity of car-bodies, especially in electric-car construction, where apparatus of considerable weight is carried below the floor, is generally low, so that the fraction k/l is usually not great, and in some cases its consideration may be neglected in what follows. It is clear, however, that, inasmuch as the rail-pressure upon the rear truck is that which limits the brake-shoe pressure upon either, we are concerned only with the

conditions relating to the rear truck, and any conclusions reached regarding the application of brakes to that truck, are also applicable to the forward truck.

Fig. 2 represents the rear truck, to which is applied the vertical car-body pressure P_2, midway between the wheels, and the horizontal reaction H from the car-body, opposing the retarding force applied by the truck to the car body, at a height h above the rails. The rails have been removed and in their place the rail-pressures R_1 and R_2 and the corresponding rail-frictions T_1 and T_2 are indicated by arrows, as applied, respectively, to the forward and rear *pairs* of wheels. It may be noted, in passing, that, although each wheel has a separate rail-pressure and rail-friction, the pair

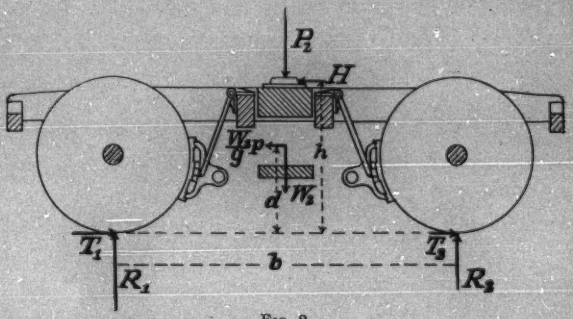

FIG. 2.

of wheels mounted upon the same axle are rigidly secured together, so that, if one turns or slides, the other must accompany it, and the simpler method of treating the pair as a single element, operating under the sum of their rail-pressures and brake-shoe frictions, is subject to no objection of any kind. The weight (W_2) of the truck is represented by an arrow, acting vertically downward through the center of inertia, at a point midway between the wheels and at a height d above the top of the rails. These constitute all the real forces acting upon the truck from without. (Although other forces, due to the brake-shoes and apparatus, act coordinately, they are altogether internal forces and therefore have no influence upon the relation of the truck to external masses.)

Each elementary portion of the mass of the truck is retarded and, through the resistance of its inertia, absorbs a portion of the retarding force, such resistances constituting a system of imagin-

ary forces equivalent to the horizontal force $W_2 p/g$, acting at the center of gravity, in a direction opposite to that of the retarding forces T_1 and T_2. From the equality of the real and imaginary forces, the following relations are evident:

$$R_1+R_2-W_2-P_2=0, \text{ or } R_1=W_2+P_2-R_2$$

$$T_1+T_2-H=\frac{W_2 p}{g}, \text{ or } T_1+T_2=H+\frac{W_2 p}{g}$$

$$W_2\frac{b}{2}+P_2\frac{b}{2}-R_2 b-H h=\frac{W_2 p}{g}d, \text{ or}$$

$$R_2=\frac{W_2}{2}+\frac{P_2}{2}-H\frac{h}{b}-\frac{W_2 p}{g}\frac{d}{b}$$

Also, combining the first and last of these equations,

$$R_1=\frac{W_2}{2}+\frac{P_2}{2}+H\frac{h}{b}+\frac{W_2 p}{g}\frac{d}{b}$$

Giving H and P_2 the values already found, the last three of these equations become, respectively,

$$T_1+T_2=\frac{W_1+2W_2}{2}\frac{p}{g}$$

$$R_2=\frac{W_1+2W_2}{4}-\frac{W_1 p}{2 g}\left(\frac{h}{b}+\frac{k}{l}\right)-\frac{W_2 p}{g}\frac{d}{b}$$

$$R_1=\frac{W_1+2W_2}{4}+\frac{W_1 p}{2 g}\left(\frac{h}{b}-\frac{k}{l}\right)+\frac{W_2 p}{g}\frac{d}{b}$$

Here again, comparison of these values of R_1 and R_2 shows that, beside reducing the rail-pressure upon each pair of wheels of the rear truck, to the extent of $p k W_1/2 g l$, the effect of applying the brakes has also been to transfer from the rear to the forward pair of wheels the weight

$$\frac{1}{2}\frac{p}{g}\frac{h}{b}W_1+\frac{p}{g}\frac{d}{b}W_2;$$

and, as the front pair becomes the rear pair of wheels upon reversing the direction of motion of the car, the available wheel-pressure for braking purposes has been reduced from

$$\frac{W_1+2\,W_2}{4}$$

for each pair of wheels, to

$$\frac{W_1+2\,W_2}{4}-\left\{\frac{W_1}{2}\,\frac{p}{g}\left(\frac{h}{b}+\frac{k}{l}\right)+W_2\,\frac{p}{g}\,\frac{d}{b}\right\}$$

From the first of the last three equations,

$$p=2\,\frac{T_1+T_2}{W_1+2\,W_2}\,g$$

For simplicity and greater convenience, $W_1+2\,W_2$, the weight of the entire car, may be designated by W and thus

$$p=2\,\frac{T_1+T_2}{W}\,g$$

Applying this value of p in the expressions for R_1 and R_2,

$$R_2=\frac{W}{4}-\left\{W_1\left(\frac{h}{b}+\frac{k}{l}\right)+2\,W_2\,\frac{d}{b}\right\}\frac{T_1+T_2}{W}$$

$$R_1=\frac{W}{4}+\left\{W_1\left(\frac{h}{b}-\frac{k}{l}\right)+2\,W_2\,\frac{d}{b}\right\}\frac{T_1+T_2}{W}$$

It is to be observed that these expressions for the rail-pressures of the rear and forward part of wheels of the rear truck are true for any rail-frictions, T_1 and T_2, that may be available. If f_1 denotes the coefficient of static rail-friction, the maximum values of T_1 and T_2 are f_1, R_1 and f_1, R_2, respectively. If then for R_1 and R_2, their corresponding values T_1/f_1 and T_2/f_1, respectively, be substituted, the above equations may be solved for T_1 and T_2, and their values found for the condition of maximum efficiency. They are

$$T_1=\frac{f_1\,W}{4}\,\frac{W\,b+2\,f_1\,(W_1\,h+2\,W_2\,d)}{\left(W+2\,f_1\,W_1\,\frac{k}{l}\right)b} \qquad (1)$$

$$T_2=\frac{f_1\,W}{4}\,\frac{W\,b-2\,f_1\,(W_1\,h+2\,W_2\,d)}{\left(W+2\,f_1\,W_1\,\frac{k}{l}\right)b} \qquad (2)$$

In order to understand now what results from this transfer of weight in practice, where it is customary to apply to each wheel the greatest brake-shoe pressure that will slide none of them, let $T_1 = T_2 = f_1 R_2$ be substituted in the value of R_2; then, upon solving the equation,

$$T_1 = T_2 = \frac{f_1 W}{4} \cdot \frac{W b}{W b + 2 f_1 \left[W_1 \left(h + \frac{k}{l} b \right) + 2 W_2 d \right]}$$

The average conditions for the passenger cars of steam-railroad service are fairly represented by the values $b = 84''$, $h = 34''$, $k = 32''$, $l = 480''$, $d = 21''$, $W_1 = \frac{3}{4} W$ and $W_2 = 1/6\, W$. Assuming that, in safe average practice, $f_1 = .25$, it is thus found that, instead of a maximum rail-friction of $f_1 W/4$, for each pair of wheels, as ordinarily supposed, the maximum is but $.834\, f_1 W/4$.

This serious loss of available retarding force induced the writer some time since to investigate the conditions for the purpose of finding, if possible, a means of automatically proportioning the brake-shoe pressure upon the forward and rear wheels of the truck, so that they should more nearly correspond to the rail-frictions of equations 1 and 2. Using the above values of b, h, k, l, d, W_1 and W_2, in those equations, $T_1 = 1.151\, f_1 W/4$ and $T_2 = .806\, f_1 W/4$, so that $T_1 + T_2 = .978\, f_1 W/2$ might be realized, while only $.834\, f_1 W/2$ is ordinarily attained in practice. Any means of making the possible rail-friction of the forward pair of wheels fully available would thus increase the braking efficiency more than 17 per cent.

The investigation disclosed the fact that a structural feature of truck brake-gear that had been found to complicate the application of brake-shoe pressure to the wheels, might be so employed that it would serve almost entirely to recover this lost efficiency in braking. It is, in brief, the angularity of the hanger-link, by which, if the brake-shoes be applied upon the inner face of the wheel—that nearest the center of the truck—and the hanger-link supporting the brake-shoe be inclined at a proper angle with the tangent to the wheel at the center of the bearing surface of the brake-shoe, the brake-shoe pressure is proportioned to the wheel pressure. This matter merits very careful consideration.

More as a matter of convenience than for any other apparent reason, it has generally been customary, in passenger-car construction, to suspend the brake-shoes from the end-timbers of the truck at the outer face of the wheels. It is true that the brake-

shoes are thus more accessible for renewals, but the arrangement is inconvenient in other respects, requiring the disconnection and often the removal of the brake-beams to remove the wheels. The application of the brake-shoes at the outer face of the wheels results in an upward thrust of the brake-hangers, proportional to the brake-shoe friction, upon the end-timber at the rear end of the truck, and a corresponding downward drag upon that at the forward end. It has already been shown that the retardation of the car by the rail-friction produces a rotative effect upon the truck, which is greatly augmented by this direct action of the brake-shoe friction through the hanger-links, and the result is that a considerable rotation or tilting of the truck frame acutally occurs, compressing the forward equalizing-bar springs and relaxing those at the rear. The reaction or recoil of these springs is the cause of the frequently observed violent backward surge or shock, so disagreeable to passengers and sometimes throwing unguarded standing persons to the floor, at the instant of stopping. If, however, the brake-shoes were suspended at the inner face of the wheels, the upward thrust of the hanger-links would act upon the forward portion of the truck-frame, and the downward thrust upon the rear portion, so that the effect would be to counteract and neutralize, instead of aggravate, the disagreeable influence of the rail-friction.

Another and still more serious objection to this method of suspending the brake-shoes is the evil effect of the angular inclination of the hanger-links, which is not only desirable to insure clearance of the shoes from the wheels when the brakes are released, but is usually unavoidable for constructive reasons. This feature will be better understood upon further consideration of the effect of inclining the brake-beam hanger-links.

Fig. 3 represents the outlines of the usual form of passenger-car truck, in which are indicated by arrows the forces applied to each brake-beam. These forces are not all in the same lateral plane, the actuating brake-force P from the brake-cylinder being applied at the center of the brake-beam, while one-half of each of the other three forces is applied to the brake-shoe at each end of the beam; but it is simpler and without objection to treat them as represented. The forces Q_1 and Q_2 are the reacting pressures of the forward and rear pairs of wheels, respectively, upon the brake-shoes; the forces F_1 and F_2 are the corresponding frictional forces resulting from the pressures Q_1 and Q_2; and the forces V_1 and V_2 are the reactions upon the brake-shoes from the hanger-

links. The center of the brake-shoes should be about three and one-half inches below the center of the wheels, and the angle between the radial direction of the pressures Q_1 and Q_2 and the horizontal, is

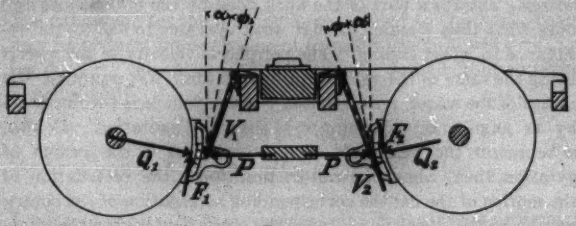

FIG. 3.

designated by a. The mean frictional forces F_1 and F_2 consequently incline at the same angle with the vertical. The inclination of the hanger-links to the tangential direction of the frictional forces F_1 and F_2 is designated by φ. The forces being resolved into rectangular components, with reference to the direction of the hanger links of each pair of wheels, the following relations are evident:

$$Q_1 \cos \varphi - F_1 \sin \varphi - P \cos (a+\varphi) = 0$$

$$Q_2 \cos \varphi + F_2 \sin \varphi - P \cos (a+\varphi) = 0$$

If the coefficient of brake-shoe friction be designated by f_2, then, whatever be its value, $F_1 = f_2 Q_1$ and $F_2 = f_2 Q_2$. Replacing Q_1 and Q_2 by their values in terms of F_1 and F_2, these equations may be combined and solved for φ and P, with the results that

$$\tan \varphi = \frac{1}{f_2} \frac{F_1 - F_2}{F_1 + F_2} \tag{3}$$

$$P = \frac{(F_2+F_1) \cos \varphi - f_2 (F_1 - F_2) \sin \varphi}{2 f_2 \cos (a+\varphi)} \tag{4}$$

In retarding the motion of the vehicle, the friction of the brake-shoes must resist rotation of the wheels to the same extent that the rail friction urges continued rotation; but, in addition, it must also destroy the rotative energy of the wheels. That is, the stored energy due to the rotary motion of the wheels, which is

entirely independent of the energy due to the motion of translation (and which would still consume considerable work if the simple motion of translation of the entire vehicle, wheels and all, could be overcome by means not affecting the rotation of the wheels), absorbs a part of the work done by the brake-shoes and only what then remains of that work operates to excite rail-resistance to wheel sliding. The peripheral velocity of the wheels being the same as the velocity of translation, if r_1 represent the radius of the wheel, a retardation p of the vehicle is accompanied by an angular retardation p/r_1 of the wheel's rotation. If, also, w represent the weight of each wheel and r_2 the radius of gyration, then, when the rail-friction causes the retardation of the motion of the car the corresponding retardation of the rotary motion of the wheels requires at the surface of each wheel a retarding force equal to $w r_2^2 p/g r_1^2$. By careful computation, the square of the radius of gyration of car wheels is found to be almost exactly six-tenths of the square of the wheel-radius. Therefore, the brake-shoe friction being required to supply both retarding forces, the relation between the wheel-forces of the two pair of wheels is obviously

$$F_1 = \frac{1.2\,w}{g}\,p + T_1$$

$$F_2 = \frac{1.2\,w}{g}\,p + T_2$$

If now the maximum rail-friction which may exist with the unequal distribution of weight upon the different pairs of wheels, as found in equations 1 and 2, is to be realized, it is necessary that the brake-shoe frictions F_1 and F_2 shall correspond with those rail-frictions. Giving T_1 and T_2 the values of equations 1 and 2, respectively, and giving p the value found for it, these brake-shoe frictions become

$$F_1 = \frac{f_1 W}{4}\,\frac{(W + 4.8\,w)\,b + 2 f_1 (W_1 h + 2 W_2 d)}{\left(W + 2 f_1 W_1 \frac{k}{l}\right) b}$$

$$F_2 = \frac{f_1 W}{4}\,\frac{(W + 4.8\,w)\,b - 2 f_1 (W_1 h + 2 W_2 d)}{\left(W + 2 f_1 W_1 \frac{k}{l}\right) b}$$

Applying these values in equation 3, it becomes

$$\tan \varphi = 2 \frac{f_1}{f_2} \frac{W_1 h + 2 W_2 d}{(W + 4.8 w) b} \qquad (5)$$

The expression for the braking force applied to the brake-beam may be given a more convenient form for practical work by giving $F_1 - F_2$ the value $f_2 (F_1 + F_2) \tan \varphi$, desired from equation 3, and, finally,

$$P = \frac{f_1}{f_2} \frac{W}{4} \frac{W + 4.8 w}{W + 2 f_1 W_1 \frac{k}{l}} \frac{(1 - f_2^2 \tan^2 \varphi) \cos \varphi}{\cos (a + \varphi)} \qquad (6)$$

Thus, by hanging the brake-beams between the wheels, instead of outside, and inclining the hanger-links at a proper angle, the increased pressure and consequently the increased friction of the brake-shoes upon the forward pair of wheels and the diminished pressure and friction of the brake-shoes upon the rear wheels, due to the effect of the friction itself in causing the shoes to press more or less forcibly upon the wheels through the angularity of the hanger-links, are made to correspond with and compensate for the transferred weight from the rear to the forward wheels. In the same manner that running in the opposite direction causes a reversal of the conditions for the transfer of weight, so, too, the rotation of the wheels in the opposite direction causes a reversal of the effect of the inclined hanger-links, and the increased brake-shoe pressure is always applied to the wheels carrying the increased weight.

It will now be more clearly understood why inclination of the hanger-links of outside-hung brake-beams has an evil effect upon the efficiency of the brakes. As the link must necessarily be so inclined, if inclined at all, that the upward movement of the wheel surface upon the brake-shoe increases the brake-shoe pressure, the pressure is *increased* upon the *rear* pair and *reduced* upon the *forward* pair of wheels when the brakes are outside-hung. Thus, the high brake-shoe pressure is always applied to the wheel carrying the reduced weight and the reduced brake-shoe pressure to the wheels carrying the increased weight. The braking force P upon the brake-beam must therefore be so reduced that the rear pair of wheels shall not be caused to slide, and the combined friction of the brake-shoes upon the two pair of wheels is thereby reduced accordingly. The loss of more than 15 per cent. in

braking efficiency, which has been shown to result from the use of a uniform brake-shoe pressure instead of pressures proportioned to the rail-pressures, occurs when the hanger-links are not inclined; but it will now be understood that, with outside-hung brakes having the ordinary inclination of hanger-links, the loss is considerably greater, the retardation probably averaging at least 20 per cent. below that attainable by the expedient of inside-hung brakes with properly inclined hangers.

In practice, the application of this method of inclined hanger-links is not without some difficulty. The chief trouble is that no constant angle of the links can be maintained, as the wearing away of the brake-shoes, together with wearing and turning down of the tires of steel-tired wheels, causes constant and considerable variation. Thus, if the angle of inclination and the braking pressure be calculated for the conditions existing when the brake-shoes and wheels are new, the increased angle when the shoes become much worn and the tires have been well turned off, would probably cause the forward wheels to slide upon the rails. On the other hand, if the calculations be made for turned wheels and worn shoes, the rear wheels would probably slide when the wheels and brake-shoes are new. It is therefore necessary to compromise between the extremes, in reference to the angle of inclination of the hanger-links, by inclining the hanger-links at the angle determined from equation 5, when the brake-shoes and wheels are each *half-worn*, and the brake-beam force must then be so established that neither pair of wheels shall be caused to slide in the extreme positions of the hanger-links. The brake-beam force determined by equation 6 would be too great for the forward pair of wheels when the brake-shoes and wheels are fully worn, and also too great for the rear pair of wheels when the brake-shoes and wheels are new. The maximum safe brake-beam force for the forward pair of wheels may be determined from the rail-pressures and the values of the angles α and φ when the brake-shoes and wheels are fully worn, and that for the rear pair from the corresponding conditions when the brake-shoes and wheels are new, and the least of the two is the greatest brake-beam force that can be continuously employed. It is found that the angular variation from the position of the hanger-link when the brake-shoes and wheels are half worn is a little less when the brake-shoes and wheels are new than when they are fully worn, and the brake-beam force to be employed in practice must be determined by the conditions existing when the brake-shoes and

wheels are fully worn. It is obvious that the variation of the angularity of the hanger-links, through the allowance necessary for wear (2¾ inches for steel-tired and 1¾ inches for chilled cast-iron wheels), is an inverse function of the length of the hanger-link itself, which should therefore be as long as practicable. With the use of that form of brake-shoe holder or head in which the hanger-link pin is located behind the center of the brake-shoe (illustrated in Figs. 2 and 3, above), the maximum length of hanger is secured. The form of brake-head in which the pin is considerably above the center, shortens the hanger materially, and its use should be avoided.

Whether the maximum rail-frictions are developed by corresponding brake-shoe frictions or not, it is to be observed that the relation between the frictions F_1 and F_2 expressed in equation 3 is one that always exists, being dependent simply upon the angle of inclination of the hanger-links and the coefficient of brake-shoe friction and independent of everything else. Therefore, even though the angle of inclination varies with wear, and the construction of the truck may be such that the full inclination of the hanger, necessary to the greatest efficiency, cannot be employed, a portion of the added efficiency of the system may still be realized by inclining the hanger-links as much as may be consistent with proper length and the limitations of the truck construction, and by employing a corresponding brake-beam force. As the inclination of the hanger-links is insufficient to compensate fully for the reduced rail pressure upon the rear pair of wheels when the brake-shoes and wheels are half worn, the brake-beam force must in this case be determined with reference to that pair of wheels when the brake-shoes and wheels are new.

The problem thus resolves itself into so laying out the truck brake-gear that the center of the half-worn brake-shoe shall be at the proper distance (3½ inches) below the center of the half-worn wheel, and that the hanger-link (as long as possible) shall stand at as great an angle to the wheel-tangent as possible (not exceeding the angle of full compensation, where it has the value found from equation 5 *when the brake-shoes and wheels are each half worn*, and then calculating the brake-beam force P for the angles φ_1 and α_1 that exist *when the brake shoes and wheels are fully worn*, if the angle of full compensation has been employed, or for the angles φ_2 and α_2, that exist *when the brake-shoes and wheels are new*, if an angle less than that of full compensation has been employed. To facilitate the application of the principle of

inclined hanger-links, the various angles of inclination for half-worn brake-shoes and wheels, and the corresponding braking forces have been determined for different conditions, as to truck wheel-base and diameter of wheel, and are tabulated below.

It will be observed in equation 5 that the angle of inclination of the hanger-links varies inversely with the wheel-base of the truck, which is fortunate, since long wheel base is desirable also in all other respects (ease of riding, minimum wear and tear of wheel-flanges and truck-frames, etc.), except in cases where curves are so sharp that long wheel base interferes with curving. The full compensating inclination of long hangers may be employed, or any size of wheel, where trucks have a wheel-base of 8 feet; and, for wheels of 33 and 36 inches diameter, it may also generally be employed where the wheel-base is 7½ feet. With passenger-car trucks of ordinary construction, partial compensation may be obtained, for wheels of larger diameter than 36 inches, where the wheel-base is 7½ feet; and, for 33 and 36 inch wheels, it may also be obtained where the wheel-base is but 7 feet. Shorter wheel-base than 7 feet, while requiring a large angle of inclination of hanger-links, provide insufficient room for an inclination of any value, unless the hanger-links are so short that the variation of the angle impairs its utility, or the trucks are low, so that the height h is also reduced as the wheel-base b is reduced.

The method of applying the principle, in cases where the full compensating angle of inclination can be used, depends primarily upon the relations expressed in equation 3. As the braking force must be so established that the forward pair of wheels shall not slide when the wheels and brake-shoes are fully worn, the friction of the brake-shoes upon that pair of wheels must correspond with the rail-pressure at that time, and the friction of the brake-shoe upon the rear pair of wheels will necessarily be

$$F_2 = \frac{1 - f_2 \tan \varphi_1}{1 + f_2 \tan \varphi_1} F_1$$

as found from equation 3, in which φ_1 is the value of the angle of inclination the hanger-link to the wheel tangent when the brake-shoes and wheels are fully worn. It has been shown that

$$F_1 = T_1 + \frac{2.4\,w}{W}(T_1 + T_2)$$

and that

$$F_2 = T_2 + \frac{2.4\,w}{W}(T_1 + T_2)$$

and, by combining these two equations,

$$T_1 + T_2 = \frac{W}{W + 4.8\,w}(F_1 + F_2)$$

and

$$T_1 = \frac{(W + 2.4\,w)\,F_1 - 2.4\,w\,F_2}{W + 4.8\,w}$$

The rail-pressure for the forward pair of wheels was found to be

$$R_1 = \frac{W}{4} + \left\{\frac{W_1}{W}\left(\frac{h}{b} - \frac{k}{l}\right) + \frac{2\,W_2}{W}\frac{d}{b}\right\}(T_1 + T_2)$$

If the full rail-friction of this pair of wheels be utilized, $R_1 = T_1/f_1$ and the above values of T_1 and $T_1 + T_2$ being substituted in this equation for the rail-pressure, it may be solved, with the aid of the above value of F_2 in terms of F_1 and $\tan \varphi_1$, to yield values of F_1 and F_2, which depend simply upon the available rail-pressure of the forward pair of wheels when the brake shoes and wheels are fully worn. These values of F_1 and F_2 being then applied in equation 4 and representing the value of the angle a when the wheels and brake-shoes are fully worn by a_1 the necessary braking force to be applied at each brake-beam becomes

$$P_1 = \frac{f_1}{f_2}\,\frac{(W + 4.8\,w)\,(1 - f_2^2 \tan^2 \varphi_1)\cos \varphi_1}{\left\{W + 2 f_1 W_1 \frac{k}{l} - 2 f_1 \frac{W_1 h + 2\,W_2 d}{b} + f_2\,(W + 4.8w)\tan \varphi_1\right\}\cos\,(a_1 + \varphi_1)}\,\frac{W}{4}$$

In practice, the application of this brake-beam force by the air-pressure in the brake-cylinder is through the medium of a series of levers and connecting rods, pinned together and forming the "brake-gear." A portion of the air-pressure upon the piston of the brake-cylinder is absorbed by the frictional rigidity of the brake-gear; and, as the leverage of the brake-gear is always calculated from the piston-pressure, it is necessary to make proper allowance for the frictional loss in the brake-gear. The only available results of investigation of such loss indicates that, in the ordinary form of passenger-car brake-gear, the brake-beam force is about 80 per cent. of that calculated from the piston-pressure.

As the total braking force of the car is the sum of the forces upon the four brake-beams, if the calculated braking force of the car be represented by B, it therefore becomes $B = 4\,P_1'.80$.

Examination of the practice in passenger-car construction of ordinary American steam railroads indicates quite general uniformity in respect to most of the various features which determine the angle of inclination of the brake hanger-link and the braking force. In general, for practical purposes, the average of the conditions existing is sufficiently accurate and may be taken as follows: The coefficient of rail-friction may be regarded as $f_1 = .25$, particularly as the limiting conditions are those of emergency applications. The coefficient of brake-shoe friction most apt to slide wheels is that of low speeds, near the end of the stop, and experience indicates a safe value to be $f_2 = \frac{1}{3}$. Little error will, in any ordinary case, result from making $W_1' = \frac{2}{3}\,W$ and $W_2 = 1/6\,W$. Generally, $h = 34$ inches, and $k/l = 1/15$. The height of the center of gravity of the truck varies with the diameter of the wheels; for 33-inch wheels, $d = 20$ inches; for 36-inch wheels, $d = 20.5$; for 38-inch wheels, $d = 21$; for 40-inch wheels, $d = 21.25$; and for 42-inch wheels, $d = 21.5$; the weights of wheels differ both with the diameter and the construction; a fair average appears to make $4.8\,w = .071\,W$ for 33-inch steel-tired wheels, $.080\,W$ for 36-inch, $.089\,W$ for 38-inch, $.094\,W$ for 40-inch, and $.098\,W$ for 42-inch. With these values (except those depending upon the diameter of the wheels), the maximum braking force, as ordinarily calculated, which may be used without injurious wheel-sliding, becomes

$$B = \frac{15\left(1+\frac{4.8w}{W}\right)\left(1-\frac{1}{9}\tan^2\varphi_1\right)\cos\varphi_1}{16\left\{\frac{46}{45}\,\frac{68+d}{6\,b}+\frac{1}{3}\left(1+\frac{4.8w}{W}\right)\tan\varphi_1\right\}\cos(\alpha_1+\varphi_1)}\,W$$

In cases where an angle of inclination of less than that required full compensation must be given the hanger-links when the brake-shoes and wheels are half worn, the same mode of procedure is followed to determine the braking force, except that the angles α_2 and φ_2, existing when the brake-shoes and wheels are new, are employed instead of α_1 and φ_1, and F_1 is found in terms of F_2 and φ_2 from equation 3, instead of F_2 in terms of F_1 and φ_1. Thus T_2 and T_1+T_2 are found in terms of F_1 and substituted in the expression for the rail-friction upon the *rear* pair of wheels, which yields values of F_1 and F_2 in terms of

simply the rail-pressure upon that pair of wheels and the angle φ_2. These values of F_1 and F_2, being substituted in equation 4, furnish the brake-beam force

$$P_2=\frac{f_1}{f_2}\frac{(W+4.8\,w)\,(1-f^2\tan^2\varphi_2)\cos\varphi_2}{\left\{W+2f_1W_1\frac{k}{l}+2f_1\frac{W_1h+2W_2d}{b}-f_2(W+4.8\,w)\tan\varphi_2\right\}\cos(a_2+\varphi_2)}\frac{W}{4}$$

From this brake-beam force, in terms of the rail-pressure of the rear pair of wheels and the angles a_2 and φ_2, existing when the brake-shoes and wheels are new, the corresponding braking force, as customarily calculated from the pressure upon the brake-cylinder piston, is found. When the approximate average values of the various fixed symbols are applied, it becomes

$$B_2=\frac{15\left(1+\frac{4.8\,w}{W}\right)\left(1-\frac{1}{9}\tan^2\varphi_2\right)\cos\varphi_2}{16\left\{\frac{46}{45}+\frac{68+d}{6\,b}-\frac{1}{3}\left(1+\frac{4.8\,w}{W}\right)\tan\varphi_2\right\}\cos(a_2+\varphi_2)}W$$

For convenience in applying this principle to the design of truck brake-gear, the following table has been prepared, showing the angle of compensation which the hanger-link makes with the vertical—that is, $a+\varphi$—instead of the angle φ with the tangent to the wheel, when the brake-shoe and wheel are half worn. The angle is determined by placing the center of the half-worn shoe (assumed to be when the thickness has been reduced $\frac{1}{2}$ inch), $3\frac{1}{2}$ inches below the center of the half-worn wheel, the radius of which is assumed to have been reduced $\frac{3}{4}$ inch. For convenience, also, the tangent of the angle $a+\varphi$ is given, so that, a convenient definite distance having been laid off from the center of the lower hanger-link pin upon a vertical line through it, a horizontal distance from its upper end, equal to the product of this tangent and the vertical distance so laid off, will determine a point in the hanger-link, and consequently its direction. The upper end will of course be fixed by the position in which the upper pin can be supported by a bracket from the truck-transom, the length, however, being as great as possible. The braking force is also given, as determined from the angles a_1 and φ_1 when the brake-shoe has been reduced 1 inch in thickness and the radius of the wheel has been reduced $1\frac{1}{4}$ inches, or from the angles a_2 and φ_2 when the brake-shoes and wheels are new, according as the angle of inclination of the hanger-links when the brake-shoes and wheels are half worn is that of full compensation or a lesser one. The length of

each hanger-link employed in these computations is also given. As already stated, only partially compensating angles of inclination occur for a wheel-base of 84 inches and, with 38, 40 and 42 inch wheels, for a wheel-base of 90 inches. In the other cases, full compensation occurs.

Diam. of wheel	b = 84 in.				b = 90 in.				b = 96 in.			
	l	$\alpha+\varphi$	$\tan \alpha+\varphi$	B	l	$\alpha+\varphi$	$\tan \alpha+\varphi$	B	l	$\alpha+\varphi$	$\tan \alpha+\varphi$	B
33″	19½	28°–33⅜′	.5444	.956W	20	37°–28⅜′	.7668	1.025W	20	36°– 6⅜′	.7296	1.028W
36″	18½	24 –29½′	.4555	.929W	18½	36°–16⅛′	.7338	1.016W	20	34°–54½′	.6978	1.026W
38″					20	29°–10½′	.5582	.990W	20	34°–10′	.6787	1.024W
40″					19½	26°–37′	.5011	.972W	20	33°–33⅛′	.6635	1.022W
42″					19	23°–58½′	.4447	.954W	19½	33°– 1⅛′	.6499	1.020W

NOTE:—b is the wheel base of the truck, in inches; B is the braking force, calculated from the brake-cylinder piston pressure, in terms of the weight of the car; and l is the length of the brake-beam hanger link, in inches. The evil effect of shortening the hanger link is illustrated in this table. For a wheel base of 90 inches, the braking force for trucks with 36-inch wheels is less than that for trucks with 33-inch wheels by only .002W, where the angle of inclination is that of full compensation and the hanger links are 20 inches long in each case; but, where the wheel base is 90 inches the length of hanger link may, in many cases, be no longer than 18½ inches for trucks with 36-inch wheels, and the braking force in that case is .009W less than that of trucks with 33-inch wheels and 20-inch hanger links. Had 20-inch hanger links been employed, instead of 18½ inch, for 36-inch wheels, the braking force could probably be increased about .007W above that given (1.016W).

It would be a serious oversight to dismiss this subject of truck brake-gear construction without mentioning the pernicious break-beam release spring. The custom of hanging brake-beams from the end-timbers of passenger-car trucks has been attended—in the many cases where the inclination of the hanger-links is insufficient to cause the brake-beams to fall away from the wheels by gravity—by the necessary use of springs to insure clearance between brake-shoes and wheels when the brakes are not applied. The loss of brake-shoe pressure from the use of such springs might, of course, be readily compensated by increasing the braking force correspondingly, if such loss could be determined. But these springs vary to such an extent, even when made apparently alike and applied in the same way, that allowance for their influence is well-nigh impossible. Springs, so applied to trucks that they should keep the shoes uniformly away from the wheels, are found to operate so unevenly that, to prevent the brake-shoe at one end of a beam from dragging upon the wheel, that at the other end must be permitted to stand off so far from its wheel that excessive travel of the brake-cylinder piston is necessary to apply the brakes, whereby the air-pressure in the brake-cylinder

is reduced and the efficiency of the brakes correspondingly impaired. Even if these springs were so constructed and applied that they exert a uniform influence upon the brake-beams, the inequalities of brake-shoe material cause them to wear unevenly, so that a new shoe at one end of the brake beam is often accompanied by a considerably worn shoe at the other end, and adjustment of clearance that will avoid excessive piston-travel at the brake-cylinder is impossible. The impossibility of adequately measuring and providing braking force for the resistance of these springs, added to the loss of efficiency from excessive piston-travel, or the alternative trouble from dragging brakes, renders the brake-beam release spring one of the most serious evils of modern brake-practice. By the use of inside-hung brake-beams, where sufficient inclination of the hanger-links insures brake-shoe clearance through the action of gravity, both the expense and trouble due to the release-spring is avoided.

To enter into the detail of the air-brake apparatus employed to furnish the braking force, in a paper of this character, would unduly extend it and would also be a work of supererogation. The compressed-air supply generally implies a suitable compressor upon the car, or, if operated in trains, one or more upon each train. Storage of the compressed air in sufficient quantity has, however, been satisfactorily accomplished in some cases and possesses certain advantages. The air is usually stored at a comparatively high pressure (generally 150 pounds) in large reservoirs secured beneath the car, or in any other convenient place. It is delivered through a reducing valve into the " main reservoir " of brake-operation, at the desired pressure, where it is handled in the ordinary manner. In such a system, a single air compressor, of large capacity and high efficiency, compresses the air at a station, where it is stored and charged into the car storage-reservoirs from time to time. The advantages lie in avoiding the cost of installing and maintaining compressors upon all the cars, and in cheapness of operation. The disadvantages consist of the bulkiness of the storage-reservoirs and the time required to stop and charge them, and also the limited distance that may be traversed during the intervals. Where the air is compressed upon the car, the compressor must be accessibly constructed and placed upon the car, and supplied with clean, dry air. It may be operated by steam, by a separate electric motor, or by the car-motor, through suitable connection with the car-axle, as circumstances render it expedient. Its

operation should be so controlled by a governor that it shall cease whenever the maximum storage-pressure has been attained in the main reservoir, and shall be renewed when operation of the brakes has reduced the storage-pressure to the inferior limit.

Upon the motorman's operating valve, the satisfactory operation of the brake-system in large measure depends. It must not only present the means of accurately gauging the force of brake-application and of promptly releasing the brakes, but must also define, with precision, the pressure of the air with which the auxiliary reservoirs are charged, to insure the full efficiency of braking without exceeding it to the injury of wheels and detriment of efficiency; while, at the same time, it must provide a superior pressure—that may vary considerably under different conditions—in the main storage reservoir, to insure prompt release of the brakes and restoration of pressure in the auxiliary reservoirs, without any variation of the working pressure in the latter—an exacting combination of conditions, not easy of realization, but of capital importance.

Of the apparatus for the immediate application of the brakes to the wheels, sufficient has already been said, it having been indicated that, in the single case where the unit invariably consists of a single car, simply an air-cylinder, in communication with the motorman's valve, meets all the requirements, while the conditions of every other case justify nothing short of the efficiency of the quick-acting automatic apparatus, and, where characterized by high speeds and frequent stops, the superior efficiency of the high-speed brake is essential to high efficiency of service.

The application of other forms of power than compressed air to brake-service has been practically limited to the vacuum and electricity. The limited pressure and bulky apparatus have restricted the use of the vacuum to comparatively light vehicles and it is fast becoming a mere historical feature of the development of the art of braking. Electricity has been experimentally applied in various forms of apparatus, but has only recently become recognized as a means of promising utility in practical braking. The simplicity of employing the back torque of the car motors of electric railroads for retarding purposes has appeared very attractive to those unacquainted with the objection to dependence upon that means alone. In combination with other means of retardation, so that excessive

heating may be avoided, this means of braking cars has been used with some practical success. But the application of electricity to the purpose of braking that appears to overshadow all others is that of the magnetic brake, which embodies such novel applications of old devices, with results so phenomenal, that the use of electricity as the source of braking force in electric railroad service at once occupies an interesting position with a very promising future.

The magnetic brake forms part of a combined braking and car-heating system, in the latter of which, the diverters of the ordinary car-starting apparatus are so also used as resistances for grading the current employed for braking purposes that they serve to heat the car. This part of the system is itself of such interest that, while it is a separate purpose, a brief description is excusable.

It appears to be a well-established fact that the heating effect due to the use of the diverters in starting is not alone sufficient for the practical purpose of heating the car, under the usual varying conditions of service; but when, in addition, the heating effect accompanying braking is also diverted to that purpose, the heat supply is abundant. Two systems of diverters are therefore used, one beneath the car, radiating the heat into the external atmosphere, and the other suitably arranged within the car for heating purposes and called heaters. The two systems may be so combined, according to the temperature and weather that any desired portion of the generated heat, from none of it to all of it, may be employed for heating the car, and any remaining heat is dissipated. The heat supply is, of course, intermittent, but the heaters are so constructed that they readily absorb the intermittently generated heat, and gradually and continuously supply it to the car for uniform heating. In this manner, the cost of the trolley current ordinarily required for heating purposes—an item of no mean proportions—is entirely obviated.

The brake apparatus itself consists of a combination of a track-brake with the ordinary wheel-brake. Track-brakes have long been known and variously proposed for practical use, but no satisfactory application of these devices appears to have been made. The track-brake consists of a system of brake-shoes, arranged beneath the car, directly over the rails, which may be forced down upon the rails to produce the retarding friction. There are several serious obstacles to the

attainment of satisfactory efficiency from this method of retardation. In the first place, as the weight of the car must be lifted off from the wheels and transferred to the track-brake shoes, it is obvious that the shoes must be so formed that they will guide the car upon the rails as safely and surely as do the wheels. This appears to be impracticable and, where the track-brake has been employed, only so much of the weight of the car is transferred to the brake-shoes that there still rests upon the wheels sufficient weight to enable them to guide the car securely. Thus only a portion of the weight of the car is available for rail-friction.

Again, it is manifest that the friction of the track-brake-shoes is of the same dynamic character as that of the brake-shoes upon wheels, which varies inversely with the speed and is very much inferior to the static friction of the rotating wheels upon the rails, which is the measure of the available friction of brake-shoes upon the wheels. While it is undoubtedly true that the large area of contact between the rails and track-brake-shoes that may be employed results in a track brake friction which is much superior to that of the sliding wheels (provided the entire weight is transferred to the track-brake-shoes), it is doubtful if the conditions permit the realization of as high a coefficient of friction where brake-shoes rub upon the track as where they are applied with the same force to the wheels, and it is certain that a track-brake of any construction, working upon this principle, is much inferior to an efficient wheel-brake of the "high-speed" type. The combination of a track-brake of this kind with a wheel-brake is merely an added intricacy, as the efficiency of the track brake is entirely at the expense of the wheel brake, in robbing the latter of the rail-friction upon which its effectiveness depends. For these reasons, and for the additional one of constructive complication and cost, no practical application of the track-brake has ever been made, within the knowledge of the writer, except in certain cases of street railroads with exceptionally heavy grades, where an independent track-brake system has been installed for emergency use only, in the event that the wheel-brake system should become disabled.

But the magnetic brake introduces an entirely new element, through which the track-brake not only does not interfere with the efficiency of the wheel-brake but both adds to its normal retardation and provides the operating brake-force. The track-

brake-shoe is placed between the two pairs of wheels, and, instead of being forced upon the rails through an effort from the car, is drawn to the rails by an electromagnet suspended from the car, thereby not merely adding its friction to the unimpaired friction of the wheel-brake but also actually increasing the rail-pressure of the wheels to the extent that the supporting springs for the track-shoes and magnets are in tension through the descent of the track-shoes to the rails. The construction will be better understood by reference to the illustration in Fig. 4.

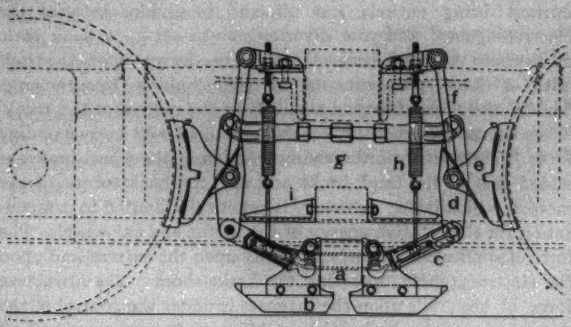

FIG. 4.

In Fig. 4, the magnetic brake apparatus is shown as applied to a four-wheeled, swiveling truck, the parts of which are in dotted lines, more readily to distinguish the brake apparatus. The electromagnet *a*, dividing the track-brake shoe *b* into two parts, is secured by pins to the two push-rods *c*, and suspended at a proper distance above the rails by the adjustable springs *h*. The push-rods are secured by pins to the lower ends of the brake lever *d*, which are connected at their upper ends by the adjustable rod *g* and are pivoted at an intermediate point to the brake-shoe holders *e*, carrying the wheel-brake shoes, and the hanger-links *f*, suspended from the truck-frame. The push-rods *c* are telescopic, as shown in the sectional view of the one at the left, so that a movement of the track-shoe toward the right, relative to the truck-frame, causes the wheel-brake-shoe at the right to be applied to the wheel and the connection *g* to be moved to the left, thereby applying the wheel brake-shoe at the left, the stop *i* preventing the lower end of the brake lever at the left from following the track-brake

shoe. A relative movement of the track-brake-shoe to the left is obviously accompanied by application of the wheel-brake-shoes through corresponding movement of the parts in the reverse order.

The brake-controlling device may be incorporated in the running controller or may be a separate device, placed by its side and operatively interlocked with it, so that neither can, through carelessness, be caused to interfere with the operation of the other. In the operation of the apparatus, the current is supplied by the motors, running in multiple as generators—the trolley current being entirely cut off, and is divided between the electromagnets and the diverter combination in such ratio as to cause the track-brake-shoes to be drawn upon the rails with a force proportionate to the braking requirements. The frictional resistance of the rails to the motion of the track-shoes causes the wheel-brakes to be applied with corresponding force. Thus, to the ordinary retardation of the wheel-brakes is added that of the track-brake and also the back torque of the motors, which latter, however, is practically limited to compensation for the rotative energy of the motor and car-wheels. The force of application depends primarily upon the current and upon the electromagnets operating the brake-shoes. The attractive force of the rails upon the magnets is under the control of the motorman up to a limit of about 150 pounds per square inch of brake-shoe surface in contact with the rails. The strength of the magnet is limited by the sectional area of the rail, acting as armature, and where the weight of the car makes a magnet of greater strength desirable, the track-shoe is divided into three parts, instead of two, and wound to form a three-pole magnet, or two combined two-pole electromagnets with one common pole.

The friction of the track-brake-shoe may also be adjusted to some extent through the angular inclination of the push-rods *c*, by which some of the weight of the car may be thrown upon the track-shoes, the levers *d* being correspondingly adjusted to reduce the wheel-brake-shoe pressure in proportion as the weight is transferred to the track-shoe. It will be observed also that the brake-shoes are hung at the inside of the wheels, so that the hanger-links may have an angular inclination to correspond with the transfer of weight from the rear to the forward pair of wheels through the influence of the retarding forces.

The incidental features of the magnetic brake are also of interest and great value. The current declines with the speed

during a stop, thereby offsetting the increased coefficient of friction at the lower speeds. In bad weather, when the condition of the rails is liable to be accompanied by wheel-sliding, the braking force operating the wheel-brake is correspondingly reduced, so that the force of application of the wheel-brake is automatically proportioned to the rail-friction which rotates the wheels. But, in addition to this valuable feature, if by chance the wheels should slide upon the rails, the interruption of wheel-rotation is accompanied by the extinguishment of the track-magnet current, through which the pressure of the brake-shoes upon the wheel is instantly relaxed and rotation of the wheels is resumed, without injury or serious loss of time.

In operation, the efficiency of the magnetic brake, under the various conditions of service, is phenomenal and far exceeds that of any other braking system for the retardation of trains, which, combined with the commercial advantage of dispensing with the use of trolley current or any other means for heating cars, seems to assure it a leading position in electric-railroad operation in the future.

Discussion at New York.

President Scott:—I think we owe a special debt of gratitude to both of the gentlemen who have prepared the papers of the evening. Both are particularly busy men, and they have gone to a great deal of pains and labor. I have been struck, as I am sure many of you have been, by the revelations which come from a scientific and experimental investigation and a mathematical analysis of what is apparently a simple thing. The applying of a brake-shoe to a wheel seems to be so simple that there is nothing of particular scientific interest or intricacy involved; but these papers present beautiful mechanical stories which reveal new things on every page. They show that there are peculiar mechanical features and unsuspected relations in the operation of even the most ordinary simple brake, and that with the more complex and intricate forms of brakes which have been devised these difficulties which at first we did not see are overcome and are advantageously utilized. We have with us this evening several gentlemen who are connected with the general subject of braking in one way or another, and we should have in our discussions some interesting phases of the subject presented. One engineer who is connected with the Manhattan Railway Company of this city is here this evening, Mr. Henry G. Stott.

Mr. Stott:—I can only congratulate the writers of these papers, particularly Mr. Parke, upon the elaborate investigations they have made into the general subject of braking. I want to say, Mr. President, that you have called on the wrong man to-night. I do not know much about the subject of brakes. My end of the system is located in the power house and sub-stations, and I am not very familiar with this problem; for that reason I do not think I could add anything to these papers as they are the work of specialists.

President Scott:—It is Mr. Stott's Business to make things go, not to make them stop. Mr. C. O. Mailloux has given special attention to high speed work of late, and I think also to the matter of braking, and we would be pleased to hear from him.

Mr. Mailloux:—Mr. President and Gentlemen: I may say, as a preface, that these papers cannot very well be discussed by any one who has not had ample opportunity to read them carefully and thoroughly. The paper of Mr. Parke, especially, is such an important contribution to railroad engineering literature, that, in order to be able to discuss it intelligently, I feel that I should have at least a week in which to study it, even though I may pretend to have some familiarity with the subject. I regard Mr. Parke as the greatest authority in this country certainly, and in the world perhaps, on the subject of brakes and braking. He has been studying it many years as a specialist, and the paper itself indicates the thoroughness with which he has handled it. His classical contributions to the literature of braking, in the *Railroad Gazette* and other similar publications, bear sufficient testimony to the depth of his study and its far-reaching importance. The

present paper of Mr. Parke is a comprehensive resumé, giving a valuable summary of the knowledge and data which are already available, and a highly intelligent statement of problems and puzzles which are still unsolved.

The President well said that we have here an apparently simple phenomenon, which is, in reality, a most complex one; and if you listened carefully to what Mr. Parke said in regard to the very irregular variation of the coefficient of friction, for instance, and if you noted the number of independent variables of which it is a function, then you would begin to realize that braking is indeed a most complicated problem. When an authority who has been studying a subject like this for as many years as Mr. Parke has, is unable to give one a clue as to what might be called a typical brake-curve, then we may indeed realize what a difficult problem we have before us. I have had to deal with the problem of braking-curves as a very important factor in high-speed traction. The problem of the predetermination of the brake-curve becomes interesting in such cases, especially when one is anxious to depict graphically the speed of the train at different instants, so as to predetermine the time and other data regarding the complete service run of the train. In the paper which I presented at the Great Barrington meeting, I referred to the subject of brake-curves somewhat gingerly. I "dodged" it somewhat, and stated very frankly that there was little or nothing about it known. I have sometimes taken from fifty to a hundred brake-curves and plotted them, superposed, in the hope that I might succeed in getting a clue to a typical curve or to an equation, empirical though it might be, which would at least enable me to represent with some degree of approximation, a general typical brake-curve. Mr. Parke, whom I have had the pleasure of knowing for some time, had previously told me of the difficulty, even perhaps the impossibility, of accomplishing this, and I realized very sadly when I came to make the experiment, that he had indeed spoken the truth. Our knowledge of the geometrical nature of the brake-curve is so very deficient that it can scarcely be considered knowledge at all.

The paper of Mr. Keiley, while it is interesting in the comparison which it gives of results obtained with actual brakes, is of perhaps greater interest to me on account of the fact that it represents at least an attempt to obtain practical brake-curves; that is, it shows an interesting mechanism, whereby one may be able to obtain data giving the coördinate points from which brake-curves actually obtained may be plotted. I stated in my paper just referred to, that it is very desirable that we should be able to obtain some sort of an idea of the geometrical character of a general or typical braking-curve I also stated, and it is well known, that these curves are quite erratic; and yet it does seem as if we might be able to arrive at certain general curves which can serve as types for the braking-curves characterizing different classes of service. The paper of Mr. Parke contains

valuable material in this direction, especially in the formula for the coefficient of friction as a function of the speed, which appears in the earlier pages of his paper. Mr. Parke succeeded in analyzing the celebrated Galton-Westinghouse experiments, and he worked out this equation some time ago. I notice with pleasure that he has carried his work a little further, making the formula applicable to higher speeds. Important and valuable are his contributions of facts relating to braking in general and, in particular, showing the manner in which the friction coefficient changes as a function of the speed; so also are the interesting data which he gives concerning certain stops, and the effect of different conditions on the track friction; and there are many others which it would take too long to point out in detail. I would especially mention the highly lucid and interesting manner in which Mr. Parke has called attention to the tilting effect of the momentum of the car body, and the resulting difference in the pressure applied to the track through the front and rear wheels of the truck; and I would also note the ingenious manner in which he proposes to remedy the difficulty by hanging the brake-shoes at a particular angle, all of which is worked out ingeniously and clearly elucidated in his paper. These constitute data of the highest technical and engineering importance, so that the paper contains material which will last for a long time. The paper will be, I have no doubt, just as useful ten years from now as it is to-day. I think that we are to be congratulated upon having had from Mr. Parke what I consider a classical contribution to the subject of electric railroading in general, and to the theory and practice of braking in particular.

PRESIDENT SCOTT:—A gentleman who is now taking up traction problems to some extent, in connection with an engineering and traction company is Mr. O. S. Lyford, Jr., and he may be able to give us some interesting points in connection with the subject under discussion.

MR. LYFORD:—I have listened with great interest to these papers. I am studying this problem at this time with especial reference to heavy electric traction service; but having gone into the matter only very recently, I am not able to throw any light on it at this meeting. As a previous speaker has said, it would be difficult for any of us to add much to the able paper which Mr. Parke has presented.

PRESIDENT SCOTT:—A gentleman who has given attention to heavy railroad work in various particulars, from both the engineering and commercial standpoint, is Mr. Calvert Townley, of New York, and possibly he can contribute something to our discussion.

MR. TOWNLEY:—I echo, in common with the other speakers, the pleasure which has been felt in listening to the papers to-night. I was impressed with the fact, particularly in reading Mr. Parke's paper, that although the subject is abstruse and contains a number of mathematical formulæ, it held the interest

of every one in the room from start to finish. The story has been told in a clear and beautiful way and makes interesting reading, apart from the value of its matter.

Tests were conducted in Boston about two years ago by the Boston Elevated Railway Company, to determine a number of braking and other questions with reference to their equipment. A train composed of three similar cars, each equipped with motors, brakes and all the other paraphernalia, was run up to practically its maximum speed, somewhere between thirty-five and forty miles an hour, and then the emergency brakes were set, current being kept on the motors. The object of the test was to determine what the effect would be first on the motors and the car equipment, and second on the speed of the train. It was found that when the train had slowed down to about twenty miles per hour, it continued at a constant speed, showing conclusively that with each car equipped, it is not practicable to stop a train by means of brakes, unless the power be shut off. This fact is easily demonstrable by a braking-calculation, but at the time named it had not been brought out so forcibly and conclusively, and there were a number of people who differed in predicting the result of the tests.

With brake-shoes placed between the wheels, nearly all brake-dust resulting from the grinding off of the shoes and tires, is thrown away from the electrical equipment. Of course, some of it does fall back on the motors, but in general the tendency is to throw the dirt away. Where the motor frames are run open, this arrangement of brake-shoes is of distinct value in keeping the motors cleaner and assisting toward a less rapid deterioration. With brake-shoes placed outside the wheels, the reverse is true, a great part of the dirt being thrown directly over the motors with consequent objectionable results.

PRESIDENT SCOTT:—Mr. W. O. Gotshall, of the New York and Port Chester Railroad Company, desires to ask some questions of Mr. Parke, and we shall be pleased to hear him.

MR. GOTSHALL:—About a year ago I was associated with Mr. Parke in a suit in which we both gave some expert testimony. He gave at that time a statement of some distances within which trains running at sixty miles an hour and less, could be stopped. I believe they asked him whether he knew anything about the relative distances occupied in stopping a train using the electro-magnetic brake and one using the air-brake. If he can answer that question at this time I would like to have him do so. Another question occurs to me, and that is, what are the relative first costs and subsequent maintenance costs of the electromagnetic brake and the high-speed or quick-acting air-brake? I have been trying to find out for some time the relative effect upon the wheels, tracks and equipment of the internal versus the external suspension of brake-shoes, which Mr. Parke describes, and I have not been able to get it.

I was somewhat surprised to learn that Mr. Townley was of the

opinion that suspending the brake-shoes inside would protect the motors. I was in Boston some time ago, and understood that they were of the opinion there was more trouble from suspending the brake-shoes inside, than there was from suspending them outside.

A series of interesting tests was shown to me some time ago between a hand-braked car and a power-braked car, under like conditions as to weights, speeds, etc. The power-brake was an air-brake. The tests were made for entirely different purposes than the one they finally served. They showed very conclusively that the energy-consumption in watt-hours per ton-mile, with the power-brake, was about 12 per cent. less than with the hand-brake. I was very dubious about it and thought there might have been an error somewhere. Subsequently another set of tests was made which showed that the first conclusions were about right. The explanation given is that the higher efficiency of the power-brake is due to the fact that the operator of the car does not run with the brakes set up half the time, as is the case with hand-brakes. A man intending to stop the car, after he has used the power-brake for a week or two, becomes accustomed to it and knows what it will do, and therefore he throws off his power first and then applies his brake; whereas he has the hand-brake partly set up all the time. That was new to me, and probably will be to some others of those present.

MR. PARKE:—I regret that I am unable to give definite answers to most of the questions Mr. Gotshall has asked. One of the first questions was in reference to the distance required to stop a car, at a speed of sixty miles an hour, with the magnetic brake. There have been no tests made with the magnetic brake that I am aware of; that is, no systematic definite tests, under known conditions, that would enable one to say how the stops compare with the high-speed brake. It is manifest, on the face of it, that the stops ought to be better, and much better than with any wheel-brake; because while with the high-speed brake even, the brake-shoe pressure is greater during the early portion of the stop, when the coefficient of friction is low, thereby effecting a compensation, and is reduced toward the end of the stop when the coefficient of the brake-shoe friction rises, the same effect may also be acquired with the magnetic brake. It is a mere question of regulation, and in addition there is also all the braking effect of the track-brake. So I can only say as a reply to Mr. Gotshall at this time, that in a general way it is evident that the stops are considerably better, though it has not been definitely shown what they are.

I am sorry I am unable to give prices. They vary a good deal with the character of the construction. One of the difficulties in exploiting the magnetic brake, is the necessity of applying it to a good many different forms of truck-construction; and that, more perhaps than any other thing, has been the cause of its requiring so much time in its development

In regard to the cost of maintenance of the magnetic brake, I doubt very much whether the latter has been in sufficiently long and extensive continued service for the matter to be determined very accurately.

In regard to the effect of inside-hung brake-beams, I can only answer with respect to the experience upon steam railroads. The effect is very much better, so far as the influence upon the cars and upon the passengers in stopping, is concerned. The surging and shock at the moment of stopping, which result from outside-hung brakes, and also the tilting of the truck during the stop, are almost entirely removed. So far as any ill-effect is concerned, I know of none whatever. The stopping-efficiency of the brake is very much increased, and without any accompanying tendency to wheel-sliding. I know of nothing that has been found in the use of inside-hung brakes in steam railway practice that has been objectionable.

MR. GOTSHALL:—In addition to the other questions I have asked, I would like to ascertain what the relative effect on the equipment would be, considering wheels and brake-shoes, between the high-speed automatic air brake and the old style of air-brake?

MR. PARKE:—Of course, so far as wear and tear is concerned, it is obvious that a greater brake-shoe pressure is accompanied by greater wear both of brake-shoes and wheels. The wheels will wear down more rapidly in having brakes upon them than in running without brakes, although it must be remembered, too, that the effect of rail wear upon wheels is very material. I know that in the early days when it was first proposed to apply brake-shoes to the driving wheels of locomotives, one of the objections which was foremost and loudest expressed, was that the tires of wheels were worn rapidly enough already, running upon the rails, without additional wear from brake-shoes; but when brake-shoes of the Ross type were employed, which wear upon the flanges and the outside of the tread and do not wear upon the portion of the tread that is worn by the rail, it was found that tire-dressing by the brake-shoes was cheaper than turning the tires in the shop, and the wear of the brake-shoes compensated upon other portions of the tire for the rail-wear at the center of the tire.

So far as the use of the high-speed brake is concerned, if any additional wear has been observed, it has never come to our knowledge. You understand that in present practice the high pressure occurs only during the early part of emergency-stops. Of course, if it be used in other kinds of service, where the emergency application is employed for ordinary service-stops, it is possible that more wear would result. I believe, that even should greater wear result, the advantage in increasing the efficiency of suburban service would far more than offset it; but so far as we have any information in regard to it, the use of the high-speed brake has been accompanied by no greater wear and tear, not even of the wheels. The brake-shoes probably wear out some-

what more rapidly, but we have heard no complaint even in regard to excessive brake-shoe wear.

MR. GOTSHALL:—Is there any difference per ton-mile or car-mile between the high-speed brake and the other?

MR. PARKE:—Not in the braking apparatus, that I am aware of. Of course, there is an additional piece of mechanism, an automatic reducing valve, which in the long run requires consideration and attention. It is simply that kind of attention which is given the rest of the air-brake apparatus; it is an additional piece of apparatus to clean and maintain, and it requires very little attention—so little attention, in fact, that it sometimes gets none at all until the ill-effect of getting no attention is observed.

MR. MAILLOUX:—I would ask Mr. Parke if the arrangement of the brakes or the ingenious method mentioned in his paper by which he proposes to get the toggle-joint effect on the front brake-shoes, has been in use for any length of time; also whether it can be used with any form of brake. Practically, that would imply the query whether it is a patented invention owned by some manufacturer or whether it is public property.

MR. PARKE:—I will answer the last question first. As I got up the device, I am sorry to say that it could not be patented, so that it is one of those things of which the public may avail itself. I presume that if I could have patented it and made the railroads pay for it, a good many of the railroads that have not done so would have adopted it. It seems to appear to the railroads when they find they can get something good for nothing, that there must be something wrong about it. I believe it is now the standard form of construction, and has been for some years upon the passenger equipment of the Pennsylvania Railroad. They adopted it some years ago and it has been in regular use on their cars, and has been similarly employed by several other roads, with entire satisfaction. The Pennsylvania Railroad found that they were sliding some wheels with the use of inside-hung brake-beams at one time. The trouble was due to some mistake in the braking power applied, which was too high; when that was corrected, the trouble ceased. So far as I know, no serious objection to the use of the method has yet been found in the practical experience of a number of years. As to its applicatoin to different forms of trucks, so as far I know there is no case in which it may not be applied if the brake-beams can be gotten inside the wheels. There are many cases, especially in electrical construction, where it is impossible to place the brake-beams inside the wheels, without some different arrangement of the motors than usually occurs. With the magnetic brake there is no effort to use a brake-beam across the truck. I did not mention that fact in my paper, and perhaps should have done so; but the magnetic brake on each side of each truck, is a unit in itself. Tie rods at such points as to be out of the way of motors, connect these units and keep the apparatus from swaying; but there is no brake-

beam, so that this form of brake is applicable where the motors occupy positions that would not permit the use of an inside-hung brake-beam.

MR. ELIAS E. RIES:—It would appear on the face of it, that by the employment of magnetism, to obtain the pressure, there would be an increase in the friction between the brake-shoe and rail, over that due to the pressure alone, which is given in the paper as being up to a limit of one hundred and fifty pounds to the square inch. I refer to the increased molecular friction between the brake-shoe and the rail due to the magnetization and independent of the pressure, and I would ask Mr. Parke if he has noticed any such effect. If this effect is present, it would seem an important advantage in connection with the electromagnetic brake.

MR. PARKE:—I will say in reply to the gentleman, that the statement regarding the limit of one hundred and fifty pounds to the square inch, refers to the limit of the magnetic attraction of the shoe toward the rail, in other words, that is the force with which the shoe presses upon the rail. No attempt has to my knowledge been made to determine whether a different coefficient of friction exists under such conditions from that which results from mere pressure, without the presence of electricity or magnetism. No systematic experiments have yet been made with this form of brake to determine its exact efficiency, and this question could only be answered with a knowledge of the efficiency of the wheel-brakes by themselves; then the added effect of the magnetic brake could be measured and the coefficient of friction determined therefrom. This has not as yet been done.

MR. RIES:—Have you noticed these effects?

MR. PARKE:—I do not know that there has been any observation whatever of the frictional effect of the magnetic brake I have not been informed that there has appeared to be any greater friction between the magnetic brake-shoe and the rail than would be accounted for by the ordinary coefficient of friction with the pressure employed.

PRESIDENT SCOTT:—The subject is open for general discussion.

MR. W. N. SMITH:—One of the most interesting parts of Mr. Parke's truly classical paper is his common-sense proof of the fact that the pressure of the forward wheels is greater than that of the rear wheels. An incident that once came under my observation as experimental proof of this, may be of interest. Any member of the INSTITUTE who has at his disposal an electric car equipped with two motors can try it for himself.

Mr. Parke has briefly alluded to the "back torque" method of electric braking, which consists in disconnecting the motors from the line and throwing them in parallel with each other, with armatures reversed. One motor then operates as a generator and tends to drive the other backward, the combination thus acting as a brake. This as an emergency operation has been well known to those operating electric railways ever since it became

the practice to use independent reversing switches for two-motor equipments. I have more than once carried a heavily loaded car and trailer down a 4 per cent. grade by this means, when the hand-brake was so bad it could not be worked. After seeing Mr. Elmer A. Sperry's original electric brake, which was brought out in 1894, I experimented a little on a 21 foot double truck street-car with maximum-traction brakes and one G. E. 800 motor on each truck, and I went through this electric-braking operation without applying the hand-brakes. While watching what was going on underneath the car, I noticed that the wheels of the rear truck would vibrate like the balance-wheel of a watch, revolving alternately backward and forward. One motor of course was bound to overpower the other, but it was always the rear wheels that slipped; and with an empty car no reason was then apparent why the rear motor should carry appreciably less weight than the forward one. Mr. Parke's statement as to the increased braking effect on the front wheels, makes it easy to see why it was always the rear motor which lost its grip and vibrated backwards and forwards.

The electric brake in its disk form, that is the fixed magnetic shoe working against a disk keyed to the axle and actuated by current from the motors working as generators, was first developed by Mr. Sperry and has been used some years. It would be a contribution to this discussion if any one present could tell us something about the operation of this form of brake.

MR. W. J. HAMMER:—As a matter of historical interest, I wish to say that any one interested in the magnetic brake may go to the Brooklyn Polytechnic Institute and there see Edison's 1880 locomotive with a passenger car, and underneath the latter a disk-brake on the axle, revolving between the poles of an electro-magnet. That identical outfit of Edison's 1880 Electric Railroad carried over 5,000 people, and attained a speed as high as forty-two miles an hour. Another interesting historical item is that Mr. Henry E. Walter, at one time chief electrician for the Edison General Electric Company at Schenectady, designed a brake which he called a hysteresis-brake with magnetic brake-shoes acting on the track-rail. When Mr. Sperry read his original paper which was referred to, I called attention to this original work of Mr. Walter, as it seemed to me an interesting development in electric brakes. I saw the system tried experimentally by Mr. Walter in London, England, in the early part of 1892.

PRESIDENT SCOTT:—The discussions which we have at our meetings now have a greater importance than they have had in the past. Our New York meetings are the fore-runners of a number of meetings which will come a little later. Since our last meeting here, meetings have been held in Chicago, Denver, Cincinnati, Pittsburg and other cities, and the attendance at some of these local meetings has been larger than at the New York meeting. One local meeting has had twice as many in attendance as there are here to-night. In addition to these local

meetings, which consider the papers that are read before the INSTITUTE, and which also have the benefit of the discussions which take place here, there are other meetings held in colleges and technical schools. I had an interesting conversation this evening with some gentlemen who are present, about our recent work along these lines, and I am sure we would like to hear of this work in the schools and colleges, in addition to hearing further discussion of the subject of the papers. I call upon Prof. W. S. Franklin, of Lehigh University, to address the meeting.

PROF. FRANKLIN:—Mr. President, I have been approaching the point of rising to discuss the papers of this evening, and with your permission I will do so now, inasmuch as my colleague, Prof. Esty, is responsible for the good work which is being done at Lehigh, along the lines of local meetings, to which you refer, and is here to speak for himself on that subject.

My mind has taken an ultra-scientific turn during the discussion, and the assurance I need in making the attempt to unburden myself I received before coming to the meeting by reason of a very satisfactory conversation I had at the dinner table with Mr. Townsend Wolcott. He and I got talking of Maxwell and with a degree of mutual understanding that was a delight.

The matter is simply this—and I do not think it has ever been pointed out before—the real limitation of quantitative mathematics in engineering. We are all familiar with the old problem of the flow of water through a pipe. Nothing in the range of practical hydraulics has been subject to more elaborate experimental study and no formula in hydraulics has been more widely discussed than the formula expressing the relation between the flow of water and the loss of head. I will say flatly that there is no such formula nor any possibility of such a formula.

We deal in physics with two distinct classes of phenomena, to both of which we attempt to apply indiscriminately the notion of quantitative relation or correspondences.

First, are those phenomena, if we may indeed dignify them by the name of phenomena, which are associated with states of equilibrium; and second, are those phenomena or real happenings, which are associated with irreversible processes. As an example of the first class, consider a quiescent gas in a closed vessel. In this case there is an absolutely definite relation between the temperature of the gas, its pressure, its volume, its density and so on; quantitative correspondences do in fact obtain.

As an example of the second class, consider a gas which is streaming through an orifice out of a small chamber into a larger one. In this case the gas has no definite temperature, no definite volume, no definite pressure and no definite density; the changes which it undergoes are strictly infinitely manifold; a complete specification of these changes would involve an infinite multiplicity of details, and these details would not be approximately reproduced if the process were repeated under conditions deviat-

ing infinitesimally from those obtaining previously. The fact is that *infinitesimal variations* of conditions may produce in general *finite variations* in the consequent trend of the dependent phenomena, and this failure of the principle of limits means absolutely the failure of all quantitative correspondences, except such as may be expressed statistically.

As another example of this second class of phenomena consider the flow of water through a pipe. Every one who has observed this phenomenon with his eyes (not through the mediation of an algebraic formula) has no doubt noticed that it is a phenomenon which exhibits in its minute details an utterly irregular succession of fits and starts. Thus, a pressure-gauge connected to a pipe through which water issues from a tank, shows irregular and rapid variations of pressure. The only vigorously logical quantitative study of the flow of water through a pipe, consists of a long series of repeated determinations of discharge under conditions which are as nearly as may be constant, and the result would be *a certain definite mean discharge, and a certain probable deviation from this mean*, that is, the results strictly speaking would be expressed statistically. There is not and cannot be a formula for expressing the relation between head and discharge. I wish my remarks to be taken suggestively, for I do not at present know precisely how to state fully what is in my mind, and I may be pardoned if I state a general conclusion, namely, that the present methods of physics do not and cannot serve to reduce the complex real phenomena, even of inanimate nature, to their ultimate elements. The phenomena of meteorology, for example, can never be systematized by present methods of physics; the principle of correspondence, or as it is sometimes called, the principle of cause and effect, in view of what I said a moment ago about finite variations in the phenomena resulting from infinitesimal variations in conditions, fails.

Now, in regard to friction, I believe (in fact, my understanding of the case amounts to much more than a belief), that in this also strict quantitative correspondence fails; there is no such thing as a coefficient of friction, nor any such thing as a functional relation between the force which pushes two sliding surfaces together and the force which is necessary to produce sliding. The whole matter is a statistical one and the scientific method for accomplishing the utmost in the braking of a train would be, first, to study the mean functional relations between *pressure* on brake-shoe, *velocity*, *temperature*, *time* and *retarding force*, and to determine the *probable variation* from this mean; then, second, to devise a brake-mechanism which would cause the pressure on the brake-shoe to vary in such a manner with velocity, temperature and time, as to make it at each moment during the stopping of a train equally improbable that the frictional force might start the wheel skidding; the exact degree of improbability being open to choice and really, if one were to take the pains, determinate.

PRESIDENT SCOTT:—Prof. Franklin has called attention to

another method of considering some elements with respect to the subject before us, and just as many different avenues of thought or consideration as we can indicate here in our preliminary discussion, just so much do we open the lines of discussion which may be pursued in the local meetings which are to follow. Prof. Franklin reminded me of a young man who had not had a particularly extensive mathematical training, who attempted to plot graphically the monthly sales of a company. As the accounts varied erratically month by month, during the year, he was not able to get a regular curve. He was much distressed as he thought a curve should be nice and smooth. He was trying to apply a mathematical method to something which did not admit of that sort of analysis, expecting to get a particular kind of result. His method was quite similar to that which Prof. Franklin has pointed out, wherein we sometimes try to apply certain physical laws to cases where they do not quite apply. We should now be pleased to hear from Prof. William Esty, also of Lehigh University.

PROF. ESTY:—President Scott has suggested that perhaps a few words about our local section at Bethlehem might not be amiss. When the proposition to have local sections was inaugurated by our President, I for one felt greatly pleased. I had hitherto supposed that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS was American in name only, and that it should properly be called the New York Institute of Electrical Engineers. I supposed this simply because I did not happen to live in the neighborhood of New York, and being out on the prairies felt beyond the reach of the INSTITUTE's influence. But now that I have moved nearer New York, approaching it, you might say, as a limit, I realize more than ever the benefit of living nearer the electrical centre of gravity. Hence, for those more distant members of the INSTITUTE, I can forseee the great advantage they will derive from this new policy. I can see, for instance, in the case of our local section, from the interest manifested from the start by the students, it is going to be a big thing for Lehigh; and I am sure by its results it will prove beneficial to the INSTITUTE, perhaps in a small way and I hope in a larger way. We have as a nucleus for our local section the electrical engineering society at the University. The seniors and juniors are active members and the sophomores studying electrical engineering are admitted as associates. We have some thirty-five or forty of the electrical engineering students in the club. We have already held three meetings, and have had a number of interesting papers presented by these students, with discussion afterwards, and you have no idea how stimulating such a reading of papers is with discussions on them, especially when the meetings are held immediately after the regular New York meetings. If things go on as they have started, and I think the enthusiasm will keep on growing, we may be able to send in at the end of the year a substantial addition to the

membership list of the INSTITUTE. If you realized how much this new policy was doing for Lehigh and other universities I know of, you would feel disposed to congratulate President Scott on his far-reaching policy in extending the influence and value of our great organization.

MR. C. O. MAILLOUX:—I was very much interested in the remarks of Dr. Franklin, not only in their application to these two papers, but to other things connected with railway work. I wish to state that Mr. Parke himself has done what he could to remove the fallacious opinions which exist about brake-shoe friction and its variability under different conditions. I remember very well that his investigations of the subject, published in serial form in the *Railroad Gazette*, constitute another valuable contribution to the subject of engineering. Dr. Franklin has shown us the physical aspects of the problem, and he has given us reasons why we should not expect constant or uniform results under these conditions. We already knew by experience that we could not expect such results. Dr. Franklin's remarks will find application in connection with another important detail of the problem of electric traction, namely, that of determining air-resistance. As we know, there are few experiments which have been made to determine the increase in train-resistance, at high velocity, due to the resistance of the air, but even the few experiments made seem to indicate a great discrepancy between the results attained, if we measure the train-resistances at different speeds, in given units, such as pounds per ton. It seems to me that the application of Dr. Franklin's remarks is obvious here, because in dealing with air-resistances we have a case where eddies, air-currents, etc., in a fluid substance, air, introduce fluctuations and variations which are exactly analogous to those in the fluid substance water, in the hydraulic example cited by Dr. Franklin. Dr. Franklin's contribution to this discussion points a useful lesson in physics, and it may give us a key to a mystery or puzzle, the solution of which is much needed.

PRESIDENT SCOTT:—Several of the gentlemen this evening have referred in complimentary terms not only to Mr. Parke's paper itself, but to his courtesy in preparing and presenting it; but that credit is not due wholly to Mr. Parke, as I will set forth. It may be remarked that the Committee on Papers enters upon an unknown field when it selects a certain subject, and then endeavors to fill up its programme. In this present case, if I recall rightly, some half a dozen or more papers were projected for exploiting different phases of the braking problem and the methods of solution. The Chairman of the Committee asked me if I would not call upon an engineer of the Westinghouse Air Brake Company for a paper. I sent a note to Mr. H. H. Westinghouse, of that Company, setting forth in a general way what was wanted; but the way in which I put it seemed to be a little too general. A conference with Mr. Westinghouse was arranged, and I called at his office one day when I was in New York. I had

armed myself with a copy of our monthly Announcement and one or two volumes of our monthly TRANSACTIONS. After looking them over, his first remark was: "Why, your papers seem to be of a pretty high grade; you want a paper of some weight, and I think the best we can do is to have Mr. Parke prepare a paper, as he can give one having the calibre you need for the INSTITUTE." So it is really due to the judgment of Mr. Westinghouse that Mr. Parke has given the main contribution to our programme this evening; and as Mr. Westinghouse is here, I will ask that he say a word or two.

MR. H. H. WESTINGHOUSE:—Mr. President, I do not think I would have said anything if you had not put the matter in just the way you did. It is quite complimentary for you to say that I recognized the character of papers required by the INSTITUTE and knew of the man who could write a paper for this evening. I am pleased to know that the paper which Mr. Parke has read has been so acceptable. I cannot add much to the discussion of the subject, except perhaps a few words along the lines of Prof. Franklin and Mr. Mailloux. I think it is true that the subject of braking is a sort of indefinite proposition, that the coefficient of friction is rather a flitting bird, and it is hard to locate its tracks definitely. Mixed up with the proposition, also, is the matter of the personal equation of the users of the apparatus. I was thinking of this phase of the question during the time when Mr. Parke was asked as to what had been done, and whether some definite results or data were available in regard to the magnetic brake. An explanation is perhaps due as to why something better in the line of comparative efficiency could not be furnished, and, in explanation, I may say it is on account of a very uncertain element in the question, and that is the man who operates the brake. As a matter of fact, we feel that we have a good apparatus in the magnetic brake, that it contains excellent elements as explained by Mr. Parke, and has an operative efficiency in advance of anything heretofore used; but, as we are manufacturers, the practical aspect of the case is one which always interests us. We have learned that the element of the man who works the brake is so everlastingly combined with the mechanism that there is no use in drawing conclusions until that factor has been tried out. Consequently, when our experiments, tentative as they were, indicated that a generally high efficiency was obtainable, we sought opportunity to put the brake into a wide general practice in Pittsburg, as we felt the necessity of finding out whether the intelligence with which the brake could ordinarily be operated would be such as to produce the effect that the mechanism itself seemed to assure. To determine that point requires considerable time; a few experimental runs, a few satisfactory stops, would prove nothing. We do not contend that the brake is entirely removed from the liability of accident; it is beyond question that there will be accidents due to the failure of the cars to stop in sufficiently short time to prevent

collision. Of course, the causes which lead to collisions are many and various; but in every instance where a new brake is employed, when an accident occurs, the explanation always reported is that the *brake failed;* and, therefore, it is necessary that it should be tried long enough and under such widely varying conditions, that those who operate it shall acquire sufficient confidence in it to apply their common sense to causes of trouble and accident, and to determine whether it was the failure of the apparatus or the conditions under which the apparatus was used, which brought about the trouble. Therefore, I may say that the reason why there is no more definite data available now is largely disclosed by the fact that we have not thought it worth while to go after it and get it, until we were assured that the device was in a fair way to receive practical application. I may say, as Mr. Parke has explained, that, so far, everything is moving well, and that we hope at some time in the future something more satisfactory may be presented in the way of data.

PRESIDENT SCOTT:—If there is no further discussion the meeting will adjourn.

Meeting adjourned.

DISCUSSION COMMUNICATED AFTER ADJOURNMENT BY W. S. FRANKLIN.

I beg leave to call the attention of the members of the INSTITUTE to a discussion which will perhaps help to convey my meaning in the statement I made regarding the failure of the principle of limits. If an infinitesimal variation of condition can produce a finite variation in results, it is evident that a finite variation of conditions might produce a stupendous variation in results. In *Science*, Vol. XIV., p. 496, September 27, 1901, I pointed out in detail how this principle may enable us to control meteorological phenomena, and I pointed out also just what kind of knowledge we must obtain in order to realize this possibility. In this discussion I mentioned perhaps too indulgently the smoke-ring cannonading of Burgomeister Stiger, which had attracted considerable attention during 1900 and 1901.

COMMUNICATION AFTER ADJOURNMENT BY R. A. PARKE.

Having had no opportunity to examine Mr. Keiley's paper before it was presented at the December meeting, I was not prepared at that time to call attention to one or two features which appear to me to call for a word of caution. Mr. Mailloux referred to the difficulties he had discovered in making any general use of formulæ for train stops, in his discussion of Mr. Keiley's paper; but it may prove advantageous and useful to point out more specifically the reasons why such formulæ are unreliable beyond the very narrow range of conditions from which they appear to have been derived.

It will be noted, first, that, in deriving the formula, it is stated on page 21 that, after the car was brought up to speed, the speed

" was found to fall off at the rate of about 0.16 miles per hour per second." It is, of course, a well-recognized fact that train resistance or car resistance is a function of the speed, and any formula which contains a constant train resistance can be applicable only to conditions which include the speed to which such resistance applies. Also, the distance run during the interval that the brakes were applied depends, in the formula, upon the initial speed at the instant of application and a constant retardation R, which is designated at the " rate of braking, in miles per hour per second, from setting of brake-shoes to stop." This quantity R is, in reality, different for every different speed, and, if determined from stops made from a speed of from 15 to 18 miles per hour, the stopping distance given by the formula would be very much too great for a speed of 35 or 40 miles per hour.

The formula for the total distance (on page 23) contains a constant quantity N; that is, one independent of the speed. The use of the constant in such a formula necessarily introduces error in the lengths of stops computed for low initial speeds, which increases as the initial speed becomes lower. It will readily be seen that the formula would require that the car should still run a definite distance if the brakes were applied when the speed is practically zero. Obviously, no formula of general application for stopping distance in terms of the speed can include a term containing the zero power of the speed.

These statements are not intended to imply that arbitrary formulæ of this kind are without practical utility. Such formulæ are very useful and even necessary in reducing the lengths of stops from known speeds to that of a standard speed, not greatly differing from those from which the test stops were made. Where competitive tests of different brakes are to be made, under definite conditions, for stops from a given speed, the actual stops will generally be made from speeds near, but usually a little more or less than, that which it is desired to realize, as it is extremely difficult to attain the exact speed desired at the time that the brakes are applied. It is then necessary, for the purpose of comparison, to reduce the actual stops to the corresponding distance for the required speed, and this may be done very satisfactorily, and with but little error, by the use of such formulæ.

Years ago, I found considerable satisfaction in the discovery of a formula of the same general character as that given in Mr. Keiley's paper—except that it included no constant term. It seemed to correspond very satisfactorily with a considerable number of train stops under known conditions, and it was not until the formula was applied to considerably greater speeds that I became very suspicious of it. I then analyzed the matter very carefully and discovered the difficulty of obtaining a formula applicable to a wide range of conditions. Where train resistance and grade influence are omitted, I found a logarithmic expression for train stops, which may be employed for any initial speed.

Train resistance is so insignificant in comparison with that of the brakes, that suitable provision may be satisfactorily made for it in the constant coefficients of the formulæ; but the effect of grade is quite a different matter, and no general expression, short of an infinite series which does not satisfactorily converge, can be found to apply satisfactorily under the various conditions of regular practice. A complicated and cumbersome approximate expression, involving the cube of the initial speed, was derived; but a sufficient number of stops under sufficiently different known conditions was not available to determine satisfactorily the constant coefficients, and the formula would have been too complicated and tedious in its application for any general use, if the constants could have been determined. Therefore, while the formula in Mr. Keiley's paper may serve well for comparison of the performance of brakes at a given speed and under specific conditions, the absence of any suggestion in the paper that its usefulness does not extend to other conditions and speeds has led me to offer these words of warning to those who may be seeking some simple means of finding the stopping distance of cars or trains from various speeds, as such formulæ are not even approximately reliable under conditions materially different from those under which the constant coefficients were derived.

It appears to me that Mr. Keiley displays considerable courage in attempting to determine the commercial value of different brakes in even a single kind of service. The problem is a most intricate and illusive one, and the reduction to a matter of dollars and cents of the various elementary items entering unto the sum total, to be charged against each brake must, in any case, become a very complicated and difficult matter. For instance, the personal element of the operator of the brake is a most important one, and is so uncertain that the most efficient and economical brake may be caused to take almost any rank from the best to the worst.

Wheel sliding, for instance—which I do not find enumerated under the features of controlling importance in the paper—should condemn a brake possessing practically all the other virtues, but subject to that failing. Hand brakes of high efficiency are especially subject to this evil; because, if adapted to the use of men of moderate strength, wheel sliding is almost certain to result under the manipulation of men of greater strength, unless the greatest care is exercised in operation. In a certain series of competitive tests, a hand brake of especial design attained the most satisfactory results of any of a number tested. In these tests, the brake was operated by a picked man, whose discretion enabled him to make the most satisfactory stops without sliding wheels; but the daily pounding of wheels with worn-flat spots under a large proportion of the cars equipped with it upon the road, clearly indicated that, in the actual service of everyday use, the same brake was a most expensive luxury, in the hands of the average operator.

Also, in reference to the matter of accidents, the rating of a brake may be made or ruined by the character of the men employed, or by the price which a company is willing to pay its employees. Moreover, a brake might be in regular and extensive operation for a number of years without any accident, and so the charge against it in the accident column of Mr. Keiley's method, at the end of that time, would be nil; but the next year an accident might occur (and perhaps under conditions or from causes for which the brake ought to be held in no wise responsible, if the operator did not find it necessary to exculpate himself), of such magnitude that the average annual cost of accidents for all the previous years would thereby become considerable. It might easily occur, during a limited period of observation, that an inferior brake would show a clear accident record, while a superior brake, more simple and sure of operation, would be subject to a heavy charge for one or more accidents, which, if the actual facts and true conditions were all known, could not possibly be attributed to fault or characteristic of the brake or of its operation. It would therefore hardly seem that any figures of this kind could be accepted as really significant of the commercial value of any particular brake, unless made up from statistics from a considerable number of roads, operating under the various different conditions of practice, and extending over a long period of years.

Meeting of the Pittsburg Local Section of the American Institute of Electrical Engineers.

(MINUTES OF MEETING HELD AT THE ELECTRIC CLUB, PITTSBURG, JANUARY 5TH, 1903.)

Programme.

Mr. C. F. Scott, Introductory Remarks.

Mr. N. W. Storer abstracted Mr. J. D. Keiley's paper, "Some Brake Tests and Deductions Therefrom."

Mr. R. A. Parke presented his own paper, "Railroad Braking."

Mr. C. Renshaw abstracted the New York Discussion.

General Discussion.

Upon motion of Mr. P. H. Thomas, a vote of thanks was unanimously extended to Mr. Parke for his very able and instructive paper.

Mr. Parke took exception to some of the general conclusions drawn by Mr. Keiley in his paper and stated that he had written a letter to the Institute setting forth at some length his views on the subject of this paper.

Mr. F. C. Newell stated that all of our data in regard to braking had been obtained from tests made under steam railroading conditions but that electric traction had introduced many new

problems. Mr. Newell said he thought the great majority of accidents which occur in electric traction are due to the inferior grade of operatives employed, and that unless a more intelligent class was obtained the best appliances that could be devised would not be sufficient to prevent many catastrophes.

Mr. Storer stated that the coefficient of friction could be very accurately measured by driving electric cars with brakes applied. Observations of the pressure applied to the brake and the power consumed by the motor would enable accurate calculations to be made.

Mr. Calvin W. Rice called for original papers from members of the Local Section, to be presented before the Section at future meetings.

Mr. Scott called attention to the style of Mr. Parke's paper, saying that it was "a beautiful story, an example of the poetry of common things."

[COMMUNICATED AFTER ADJOURNMENT BY MR. H. WARD LEONARD, IN REPLY TO PAPERS AND DISCUSSION, NEW YORK, NOVEMBER 21, PITTSBURG, DECEMBER 4, 1902].

After the meeting at New York City, Mr. Dowie presented a table giving the capacity of the rotary converter in comparison with the capacity of the propelling motors.

For the simplest form of my system, as described in my paper of November 21st, Mr. Dowie places the capacity of the generator at 148, when the motor capacity is 100. He states that this is "based on 90 per cent. efficiency and 33⅓ per cent. allowance for weakening of field."

If by "capacity," Mr. Dowie means kilowatt capacity, his figure of 148 is incorrect. I point out that the kilowatts supplied by the generator are practically identical with the kilowatts received by the motor in any of the modifications of my system, since there is no loss of energy in rheostats in the armature circuit.

If by "capacity" Mr. Dowie intends to mean the weight of the apparatus, which seems to be the only other possible interpretation, I wish to point out that the rotary converter would, of course, in practice be operated at much higher speeds than the propelling motors, and that consequently the weight per kilowatt would be very much lower for each half of the rotary converter than in the case of the propelling motors, so that Mr. Dowie's figures of 148 for the "capacity" of the generator to supply a "capacity" of 100 in the motors is quite incorrect under any possible interpretation of the word "capacity."

Mr. Dowie's table shows that by the use of my "boost and retard" system, described before the INSTITUTE November 18, 1896, and more fully described in my patent No. 572,903 of December 8, 1896, the capacity of the converting apparatus can in certain instances be reduced to one-half of that necessitated by the simplest form of the system, and that in other forms of the system the capacity of the converting apparatus can be still further greatly reduced, but at the expense of simplicity. All of the figures presented by Mr. Dowie in his table can be still further reduced, if they are intended to refer to weights, by reason of the higher speeds referred to above, and by other modifications of the system, not mentioned by him.

The printed record of the Pittsburg meeting of December 4, 1902, shows that exception was taken by certain speakers to several of the claims I made for my system, because the reason for these claims was not clear from the paper itself. I made the paper as brief as possible, expecting that in case the claims I made were not admitted, that the discussion would enable me to explain fully my basis for making the claims.

The first point questioned was my claim that the system would effect a material reduction in the cost of maintenance of the locomotives as compared with steam locomotives.

The steam locomotive has a steam boiler the depreciation of which is quite high; and the multitude of reciprocating parts and

the necessity of perfect alignment and adjustment upon a rigid wheel-base cause a depreciation which is extremely high, as compared with an electric motor, particularly when the electric motor is one in which the field current is never opened, and the armature circuit is never opened.

So far as the propelling motors are concerned, all of the depreciation met with in the series type of motors now in use, due to the sudden breaking of the main current passing through the armature and field, is entirely avoided.

This sudden opening of the circuit of the present type of series-wound motor is probably the principal cause of depreciation in the present railway motors, and it seems a marvel that the depreciation is not even more, in view of the terrific abuse to which all insulations are subjected to by this sudden rupturing of the current passing through the armature and field in series. It will be evident that the larger the series motor the worse this difficulty becomes. In my system the conditions are the most favorable possible to keep the depreciation of a railway motor to a minimum. As to the depreciation upon the rotary converter, the conditions are even more favorable; for it is entirely on springs relative to the roadbed, is in a clean, dry location and under continual observation.

The tests of this Heilman locomotive and the numerous applications of my system which have been in use for many years upon elevators, printing presses, traveling cranes, etc., show conclusively that the depreciation suggested, due to sparking at the generator brushes, is no more than that met with at the commutator of an ordinary incandescent lighting generator. Those desiring to verify this can readily do so by inspecting the elevator plants in the Singer building, the Fahys building, the Sampson building, the Gillender building or the New York Athletic Club, all in New York City.

Mr. Keilholtz, in his paper at the same meeting, in describing a coal hoist operated by a 100 h.p. motor, with my system, stated that the cost of operation and maintenance was less than that of a steam hoist. I therefore think that there can be no reasonable doubt that the depreciation of a locomotive on my system will be materially less than that of a steam locomotive.

The next point criticized was my claim that I could effect "a material reduction of the dead load necessarily hauled by a steam locomotive, represented by the part of the locomotive and tender not on drivers." It was said in criticism of this claim that the weight of the electrical equipment would be extremely great, and at least 50 per cent. larger than that required to give the necessary tractive effort on the driving wheels.

In answer to this, I refer to my statements above, from which, I think, it will be apparent that the weight of the locomotive will not be increased 50 per cent. by the added weight of the rotary converter. But for the sake of argument, I will suppose that the rotary converter does add 50 per cent. to the weight of

the locomotive; how do we then compare with a steam locomotive of equal tractive effect? Under this admission, one-third of my locomotive is an unnecessary weight, but every pound of it is on drivers and is therefore available to produce tractive effort; whereas in the standard heavy freight locomotive of to-day the weight of the tender and the part of the locomotive not on drivers is far in excess of one-third of the total weight of the locomotive and tender, and this weight, not on drivers, is of no use under any circumstances.

It does not seem to be appreciated by those making this criticism that the chief problem in the railway freight service to-day is, how to secure largely increased tractive effort in a locomotive, as the economies in freight haulage are almost directly proportionate to the tractive effort of the locomotive.

In the steam locomotive it is difficult to increase materially the number of drivers, because of the necessarily rigid wheel-base of the locomotive, which cannot be lengthened beyond a certain point on account of the difficulties in getting around curves.

The weight carried upon each driver has in recent years also been forced up to its limit upon existing roadbeds. What is needed is more drivers upon a flexible wheel-base, while keeping the weight per driver as at present, and this can be readily obtained with my system, as the parallel rods are then entirely unnecessary, although they probably would be necessary in the case of any form of series motor. In explanation of this, I point out that with a separately excited motor field, the motors could not skid and race up to full speed when starting a train, even upon a slippery piece of track; whereas with any form of series motor, the maximum joint tractive effort could only be obtained by the use of the very objectionable parallel rods, which all railway engineers would like to avoid.

My claim was questioned that the first cost of equipment for my system would be very much less than that of any system for equivalent service which involves the use of substations. This seems to me almost self-evident when one considers the tremendous reduction in the cost of copper for the transmission, and the fact that the capacity of the rotaries in the substations must be several times that represented by the average demand, in order to take care of the much heavier starting current needed, and also to provide against breakdowns or an unusual congestion of trains. With my system, the rotary converter on each locomotive has a capacity adapted to the motors and need not have any such excessive margin.

On the other hand, each substation also involves real estate and buildings. Even under the very favorable conditions for substations in London, on account of the density of the traffic, the cost of the substation system as brought out by the arbitration proceedings in the recent Yerkes case, and based upon the figures given by the advocates of the substation system, was

about $30 per kilowatt, for the rotary substations and $34 per kilowatt for conductors (*Engineering*, November 8, 1901).

With my system, the cost per kilowatt for the converters would be much less than $30 per kilowatt, and the cost of conductors would probably not exceed $10 per kilowatt. If a similar comparison were made upon the basis of trunk line freight service, instead of the heart of London, the cost of my system would not be materially affected per kilowatt, whereas the cost of the substation system would be enormously increased and in fact would become so large as to make any serious consideration of it almost absurd.

I do not admit that the series motor is cheaper per kilowatt than the separately excited motor of my system. On the contrary, I think that the separately excited motor when made in the same quantities, would be cheaper; because of the less amount of insulation needed, and the reduction of heat in the field windings, and other points of advantage leading to cheaper design and reduction of weight.

Bronxville, N. Y., Jan. 8, 1903.

Meeting of the Chicago Local Section of the American Institute of Electrical Engineers.

(Minutes of Meeting held at the Rooms of the Western Society of Engineers, December 2, 1902.)

Mr. R. H. Pierce:—In the past we have had a good deal of trouble in receiving the papers and getting them to the local members early enough to be read over before the evening of the meeting, so that the subjects have not been discussed as fully as they should have been. This year there has been a change in the policy of the Institute, as shown in the address of President Scott. The policy of the Institute now is to have a large number of papers on interesting subjects, to have the papers in hand as early as possible, and to have local organizations in each of the large cities. The idea is that the local members shall conduct their own local meetings as may seem best to them, and have meetings at regular intervals. It is also the policy of the Institute at present to have these meetings attended by anyone interested in the papers to be discussed, whether members or not, and to have anyone who is interested enough to come to the meeting, take part in the discussion should he so desire.

We have practically decided among ourselves that in order that we may be sure of having these papers, it will be well to hold our meetings about ten days or two weeks after the New York meeting, and in this way be prepared for the discussion.

The paper on an "Electrically Operated Coal Hoist, having Variable Speed Control," by Mr. P. O. Keilholtz, was then read by Mr. Peter Junkersfeld, of the Chicago Edison Company, who added:

"The particular electrically operated coal hoist, described by

Mr. Keilholtz, if it is not the one at the new power station of the Manhattan Railway Co., in New York City, is at least very similar. A satisfactory coal hoist is of course a particularly important part of such a station and a slight difference in first cost would by no means be the determining factor.

In this tall tower, something like 186 feet high, carrying clamshell buckets handling 70 tons per hour, quick handling and smooth acceleration are of vital importance. As I remember the Manhattan station, this is the only drive requiring 550 volts, and it appeared to me somewhat peculiar as to just why they selected 550 volts instead of 250, which is the voltage used on some of their other auxiliaries.

On the whole, I think Mr. Keilholtz shows very nicely one very good application of that system of control."

Other papers presented at the New York meeting, November 21st, were read as follows:

"A Series-Parallel System of Speed Control," by Mr. Geo. W. Fowler, was read by Mr. H. R. King, of the Western Electric Company.

"The Operation of Machine Shops by Individual Electric Motors," by Mr. R. T. E. Lozier, was read by Mr. Geo. B. Foster, of the Bullock Electric Manufacturing Company.

"Three Wire System for Variable Speed Motor Work," by Mr. N. W. Storer, was read by Mr. J. J. Gibson, of the Westinghouse Electric and Manufacturing Company.

"The Storage Battery as a Factor in Speed Control," by Mr. H. B. Coho, was read by Mr. O. E. Osthoff, of the Electric Storage Battery Company.

Mr. Osthoff added:

"I do not believe the arrangement shown in Fig. 1 (see page 1562, December TRANSACTIONS) is at all practicable.

As a substitute for this method might be suggested the employment of about 23 cells in a group; and four groups, say, 92 cells in all, which could be connected in multiple series. On the first notch all the cells would be in multiple; on the second notch there would be two groups in series and two in multiple, and on the third notch they would all be in series; on the last notch the cells could be cut off and the motor thrown across the supply mains. While the motor was taking current from the supply mains, the battery could be charged at a slow rate separately. In this way all the cells would be discharged equally.

Another advantage in favor of this scheme is the fact that when the greatest current is required, all the cells are in multiple, so that the battery is in the best position to give the high current. As far as the point B is concerned with this plan, the battery cannot be on charge at all times when current is flowing on the mains, but I do not believe it would make very much difference in the cost of this current. In the plan suggested here, the battery would get a continual supply of current, but by the other scheme the current would only be put into the battery when the

controller is on the last notch. This method of control is exemplified daily in the use of the automobile, as far as grouping the cells in multiple-series is concerned.

In the last paragraph on the third page he speaks of a substitute for storage batteries in the way of counter-electromotive-force cells, and ends by saying, "the cutting down of supply voltage by counter-electromotive-force is the natural method dictated by economic consideration, while to cut it down by resistance is unnatural," It is not quite clear to me what he means by one being the natural method and the other the unnatural, because the amount of energy wasted is exactly the same in the two cases, so the only advantage which the electromotive-force cells would have would be the fact that the voltage you would subtract from the mains would be the same, regardless of the amount of current flowing."

MR. PIERCE:—The system proposed by Mr. Leonard is one which gives any variation of speed control that is desired, simply by turning the handle of a field rheostat. Mr. Leonard first proposed it as a system for operating street cars. The main applications of this system have been made in connection with large stationary motors. This system has proved particularly advantageous where it is desirable to operate very large motors, and run them at speeds varying from nothing to full load, as in mining work, for operating large pumps and hoists; also for electric cranes.

At the time when the alternating current first came into use for transmission in connection with railway work, Mr. Leonard suggested the additional improvement on his system of using an alternating current motor to drive his direct current generator. With this arrangement, it is possible to transmit, with an alternating current, a very high voltage and at the same time, to use low voltage direct current motors for doing the actual traction work. In the paper read this evening, Mr. Leonard shows the additional advantage of this arrangement as a "multiple unit system." It will, of coure, be apparent that if you can vary the voltage upon one armature, you can vary it on any number of armatures at the same time, and therefore give them all the same speed. I believe Mr. Leonard's paper is worthy of great consideration, as it calls attention to the lines along which we may look for development in electric railroading.

The very men who have done the most in developing the present polyphase systems, have expressed the belief that we shall eventually come to some single-phase system. The single-phase system is the simplest of all systems, and there is a tendency in electricity, as in every art, towards simplicity in apparatus and elimination of everything that is complicated.

At first glance, Mr. Leonard's devices may seem complicated, but his system is certainly able to do away with what we are now using, which is extremely complicated and not very efficient—that is, the use of rotary-transformer substations, which call for

enormous investments in copper and machinery, and large losses in power, besides cost of attendance. It was stated by Mr. Leonard in the New York discussion, that his system was to be put into use abroad in the near future. While I am not prepared to discuss the relative efficiency and cost of his system, as compared with those now in use, it seems apparent to me that it reduces the cost of both the generating and transmission plants to a minimum, and that it will materially increase the distance over which it is commercially practical to operate long-distance railroads. The apparatus on the car will certainly pull heavier loads, and at the same time give a quick acceleration and absolute control over the motion of the train.

PROF. D. C. JACKSON:—I did not know that a meeting was to be held here to-night, nor the subject to be discussed, until this afternoon, so that I have little to say. The presentation of these papers shows how far the commercial application of variable speed motors has taken possession of the minds of the electrical manufacturers, and how far it is soon to take possession of the minds of the users of electrical machinery and machine tools. This is something that a few have foreseen as a coming necessity for perhaps six or eight years. As a witness of this, I will say that I read papers before the Western Society of Engineers and the American Society of Mechanical Engineers a number of years ago. I have never read a paper on variable speed motors before the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, as this has appeared to me to be rather a matter for discussion before and amongst the users of machine tools and electric motors, than by the manufacturers of the motors.

The reason, I think, that variable speed electric motors have not been more fully adopted by the users of machine tools and other machinery, is the delay on the part of the electrical people in the development of motors with reasonably satisfactory speed control, which could be put on the market at a price at which the ordinary user could afford to purchase them. This delay has been partially due to the fact that the electrical people have been so busy that they have not been willing to undertake any special equipments, which involve so many difficulties.

MR. B. J. ARNOLD:—There were two or three points not brought out in Mr. Lozier's paper.

The author lays considerable stress upon the increased efficiency in operation of the multi-voltage system, all of which is undoubtedly true, but that is simply an increased efficiency in the consumption of power. He failed to mention the fact that that system or any other system which requires a large number of individual motors, or a larger size of motors than would ordinarily be used for constant speed, must necessarily cost considerably more, and the interest on the increased investment more than offsets the saving in power. I did not notice that that point was touched upon in the paper. I do not make that as an argument against Mr. Lozier's particular system, but against

individual-motor systems in general, namely: that if you put a large number of individual motors into a plant, the cost per horse-power of work done runs up so high, due to the interest on the increased investment, that it more than offsets the power economy.

If my understanding is correct, that paper, as well as the others, advocates individual motors on tools, as against the grouping of a number of small tools on a piece of shafting, driven by a motor. The grouping of motors not only increases the investment greatly, as just stated, but also loses the advantage in electrical efficiency, which is gained by putting a few tools on a short piece of shafting, due to the fact that the average load of several machines is less than their maximum load. In my own experience, in every case where we have had to deal with railroad shops, when it came to buying the motors, we have finally figured on the principle of grouping the machines for all small tools.

MR. PIERCE:—In this paper I notice Mr. Lozier compares the efficiency of the individual motors with that of the grouping, and claims that it is very much more efficient to use the individual motors.

MR. ARNOLD:—He disregards the fact that the first cost is so much more when a large number of individual motors is used.

MR. PIERCE:—I do not see how he can be correct, unless he figures that they are all operated with a steady load. Your experience has been, has it not, that, taking the motors as they are ordinarily run, the efficiency of the system of individual motors would be less than with the grouping?

MR. ARNOLD:—Yes, as a general principle, because these larger sizes of individual motors are running very much at underload; and then the point I tried to make, was the fact that the first cost of these individual motors and the interest on that cost, is very much greater. The theory is a very beautiful one, and we all at first start out to put it into practice, but we generally land the other way. It is a case of the other man paying he bill. We would land sooner if we paid it. I do not want my remarks to be understood as referring to any particular system; simply the general principle of machine-shop work which has guided me in purchasing for machine-shop work, electric apparatus for railway work.

MR. GEORGE B. FOSTER:—I am very glad Mr. Arnold brought out the point of the first cost in connection with the saving effect. The saving in the fuel, as Mr. Arnold states, may not warrant the additional first cost, but while this point should not be overlooked, it is not the great advantage to be offered for the system. Machine tools equipped with individual motors show an increased output over the mechanically driven tools of from 25 to 100 per cent. This fact alone would warrant the installation of individual motors on such tools.

The result of a test on a disk 30 or 40 inches in diameter appeared in one of the trade papers recently. This disk was

first turned in a belt-driven lathe, with cone pulleys for speed changes. The time required to do the work was 60 minutes. A duplicate disk was turned by the same type of tool, except that it was driven by a variable speed motor, and the time required to do the work was 32 minutes, showing an increase in the output of a tool of this character and this class of work, of almost 100 per cent.

MR. ARNOLD:—I will admit there is a good deal in that, but whether it offsets the other or not, I am not prepared to say. I presume it does.

MR. FOSTER:—There is a large concern in the West which recently equipped new shops with machine tools driven by variable speed motors. Some of these tools in the new shop are identical with some of the tools in the old shop, except that they are electrically driven, and the work they handle is of exactly the same nature. One of the engineers reported to me that these tools were showing an average increased output over the old shop of considerably more than 25 per cent.

MR. ARNOLD:—That answer is perfectly satisfactory to me, and I have no doubt it figured out more than the increased fixed charges on the motors. It is a question of machine shop economy; a question of how much work you get out of the tool.

One point I failed to make is that I would not use this tool-grouping plan for large tools. I would put individual motors on large tools always. It is only for small tools that we should group the motors on a short piece of shafting. I would put individual motors on the larger tools, such as heavy mills, planers, large lathes, etc., and all such tools as are moved around the shop to the work.

MR. ERNEST GONZENBACH:—I have just been through the experience of the equipment of individual motors for the repair shop of an interurban railway, and it may be of interest to some of the gentlemen here for me to quote figures from memory.

On obtaining prices for individual motors, I found that the cost of the motors for driving tools, worth $6.500, would amount to nearly $4,000, and that the total horse-power capacity of the motors would have to be about 35 h.p. if individual motors were used, while by grouping the tools (two groups were finally decided upon), we were able to drive the whole outfit with two 5-h.p. motors. Of course this is not such a case as Mr. Foster refers to, but simply a case of a repair shop where a few tools would be in use at one time, and the point which Mr. Foster makes in regard to manufacturing has practically no bearing on this case.

I would like also to refer to the question of substation maintenance. I think anyone who has been connected with polyphase railways has been against that practice. It has been my fortune to be connected successively with three railways operating polyphase substations, and in every case I found that the most serious difficulty was putting into the hands of comparatively

inexperienced men the complicated equipment which is necessary in the rotary substation. It seems to be impossible to get men capable of running substations at ordinary wages. The man in charge of a substation has really more responsibility than the man at the power-house, as he has to rely entirely on his own wit in emergencies.

Another argument against substations is that in order to run a train service in any way similar to steam railroads, one has to be very careful to arrange the schedule so as not to have an undue proportion of trains or cars between any two substations, otherwise your unit in substations will require to be very large. For instance, with the Aurora, Elgin and Chicago Railway, there is a total capacity of 2,500 kw.. in rotary converters, required to be operated from a generator of 1,500 kw. capacity, simply for the reason that it is possible that there are times when trains are more numerous on one part of the road than on another. With an express service in addition to local service, it becomes readily possible that trains might call for operating a total rotary capacity two or three times the generator capacity. With the avoidance of substations, or with an alternating current system, it becomes easier to put more of that load on the power station and divide the load among a larger number of static transformer stations. I think that is a point not usually brought out in discussions of this sort.

MR. V. R. LANSINGH:—I should like to ask Mr. Arnold if he can tell me the relative cost of repairs and maintenance on the group and individual-motor systems.

MR. ARNOLD:—I would not care to answer that question without I could give you an intelligent answer. I only know about the side of it which comes to me when we are endeavoring to decide a question as to whether the saving will warrant the increased investment. I have no figures which would be of any value. The cost of maintenance, however, in shops that I am somewhat familiar with, has not been excessive.

PROF. JACKSON:—In regard to the question of grouping which my friend Mr. Arnold and others have raised, this is largely a matter of engineering common sense. If one has to deal with large engine or locomotive shops, where are found enormous machine tools, each of which requires considerable power, there is no question but that individual motors with variable speed attachments give the best result, and the individual motors undoubtedly (as shown by experience in various shops) have increased the volume of output from 20 per cent. upwards. I know of one shop where the increased output was 40 per cent., brought about by the proper employemnt of electric motors. On the other hand, in a small shop intended for a variety of job work, and where different classes of tools are used, all being more or less of small size (the individual units of the plant being idle a considerable portion of the time), grouping is undoubtedly the right thing to use. It may be taken for granted that a great

manufacturing establishment that has a reasonably uniform product—that is, a product of one kind (especially in the iron manufacturing line)—should ordinarily be greatly improved by electric drives with a great many individual motors applied to the individual tools and a large proportion of the motors of variable speed types. This statement is founded partially on a theoretical basis, but the theoretical basis has been completely borne out by the experience I am familiar with.

MR. PIERCE:—It seems to me that regardless of the question of economy in the use of variable speed motors, there is no doubt about their advantages. In most cases, the saving in power is a comparatively small matter. The cost of the fuel in an ordinary manufacturing establishment commonly amounts to only 3 to 5 per cent. of the cost of the product. Should the output be increased 20 per cent. or a great deal less than 20 per cent., the advantage would amount to more than the total saving in fuel.

The question before us this evening is the various *methods* of obtaining this variable speed control, and we would like to have as much discussion on that as possible. I will call upon Mr. Cutler, who, I believe, has had a very variable experience in that line.

MR. CUTLER:—I think I can speak on this subject from an unbiased standpoint; possibly more so than the people who have written these papers, for the reason that about the first thing I noticed was that each and every one of them advocated the system promulgated by his own company, and we, of course, must expect to see the good points set out prominently, and the other points absolutely neglected.

I will take up the papers as they were presented, and endeavor to point out the other side of the question, which I presume is entirely in order from the standpoint of this association and what the discussion is intended for.

The first paper, I believe, advocated the Ward-Leonard system for the use of controlling apparatus for hoisting coal. Now, there are two difficulties in using this system for that purpose:

In the first place, it is very slow to act. The first thing desired is to get as much coal out of that vessel in a certain time as possible. It is not possible to alter the field strength of a generator in a few seconds of time. I think that is perfectly understood by motor manufacturers, and it is not necessary for me to point out the reason.

The second reason is that the system compels the use of a plain shunt-wound motor, which will not pick up the load as quickly as a plain series-wound motor. That question does not need any discussion.

It appears to me that the best system for operating large coal hoists is one similar to several that my company have in operation, in which we use a plain series-wound motor with ordinary armal ture resistance, controlled by magnets, which eliminate al-

sparking. These magnets are energized by means of an independent lever, retarded by a dash-pot, thereby obtaining, with proper adjustment, the maximum speed acceleration that it is possible to get out of a motor. We have several very large plants in operation on this principle.

The next paper was by Mr. Lozier, in which he advocates the multi-voltage system. Discussion has already taken place between Mr. Arnold and Mr. Foster, in which the fact was brought out that there was a great saving in the output, but this does not by any means prove that that increased output is due to the use of the multi-voltage system. There are plenty of other systems which can be used. On this subject I might say that it is absolutely necessary for me in my business, when any particular application of the motor is brought up, to have some system which I can freely recommend as appearing to me to be the best suited.

My idea of operating machine tools is to let the motor alone as far as possible and to learn our lessons from the automobile manufacturer, and use sliding gears, etc. This will give a motor which is not too large for the work and can be put in at the minimum cost and will give exactly the requirements which are necessary for the machine to do its work. There are several disadvantages with respect to the multi-voltage control, but the time is so limited I will not discuss them now.

Mr. Storer's paper relates more particularly to a method of obtaining a three-wire system from a single generator, and advocates variable speed by using the extreme limit of shunt field regulation. He has apparently gone to the extreme in that matter.

The next paper was by Mr. Geo. W. Fowler, advocating the use of what is known as the "C. & C. Series-Parallel" system. There are several methods of operating printing presses which have not been brought out at all. I am a firm believer in the double motor drive system, for the reason that this system gives the actual speeds required in practical work at good economy. There is no necessity in practical work of providing for an unlimited number of steps, from minimum to maximum speed.

The storage battery system of operating printing presses, I would look at with a good deal of mistrust, especially if we have to use storage batteries in multiple-series connection.

I think the whole question of motor control sifts right down to the "survival of the fittest," and selection of the proper system. As a rule, the consumer is overwhelmed with a number of salesmen, all talking their particular system, and he does not know what to use. There is simply one remedy—let him consult the engineer and we will all be benefited thereby, as well as the consumer.

While there is a good deal of room for improvement in motor control, I feel perfectly confident in stating that there are reliable systems for almost every practical application that comes up, that

the consulting engineer is able or should be able to recommend to his customer, independent of any particular hobby which any particular manufacturer may have to recommend for his own private commercial reasons.

MR. PIERCE:—I would like to ask Mr. Cutler his views on the amount of speed regulation practical for shunt control. The Westinghouse representative says they can get 2 to 1 variation in speed, and the paper read by Mr. Foster states that 30 per cent. is all that is practical.

MR. CUTLER:—I stated that I did not advocate personally any material change, for the reason that it does not correspond with the requirement of the tool. That is, in the machine tool the torque must increase as the speed decreases, which you cannot get commercially out of a motor without using an abnormally large one, and I do not advocate any change in the speed of the motor greater than possibly the 20 per cent. variation, or 15 per cent in the shunt field.

MR. FOSTER:—Would not the installation and operation of special gears be rather cumbersome?

MR. CUTLER:—No, it is perfectly practical to do that.

MR. FOSTER:—In my experience I found it was more expensive to adapt a special set of gears to a tool for acquiring a wide range of speed, than putting in larger motors, and after they were adapted, they could not be operated with the same facility as the motor with the controller.

MR. CUTLER:—I maintain that I do not think it is possible to supply a large motor as cheaply as you can use sliding gears.

MR. F. J. PEARSON:—As I understand this discussion, it was intended to cover more particularly the relative merits of the various systems of speed control outlined in the several papers presented this evening.

In this connection, I desired to ask if we can hear something in regard to the comparative first cost, as well as cost of operation of the multi-voltage system of control as compared with the variable field method, interest, depreciation and losses considered. Take a case requiring a certain horse power, with a 50 per cent. speed variation, would we be justified in using the multi-voltage system at a higher first cost and consequent higher interest charge, as well as depreciation, as against the employment of a larger motor frame with a single standard voltage and a 50 per cent. speed variation, by the variable field method.

I understand that the cost of the multi-voltage system is about 60 per cent. higher than the variable field control method for the same horse power, and with a ratio of speed control of two to one.

MR. FOSTER:—The case you cite is not an average case. Take the average machine shop with a 2 to 1 ratio, and it will not cover the average range of work to be handled. For the particular case you cite, I would not advocate a multiple voltage system with a range of six voltages for only 50 per cent. variation in speed. Instead of the case which you cite, suppose you had a truncated

cone to be turned, the smaller diameter 2 inches, the larger 30 inches. With the speed range of 2 to 1, this piece of work could not be handled with any degree of success. If, however, you had a 7½ to 1 range with a back gear, giving an actual variation of 15 to 1, with 52 different steps, you can readily see what a saving of time could be effected in doing this particular piece of work.

MR. PEARSON:—In using the expression 2 to 1, I was in error. I should have stated, a total speed variation of 50 per cent.

MR. FOSTER:—The three-wire system described by the representative of the Westinghouse company, is a modified multiple voltage system, having two steps. The number of wires installed and combination of voltages can be carried indefinitely, but as I stated before, if only 50 per cent. variation in speed were required, I do not think that a representative of the Bullock company would advocate a multiple voltage system having six different voltages.

MR. PEARSON:—The point I was trying to bring out was the relative cost of the two methods of control; that is, whether or not the saving in the multiple system would offset the interest on the investment on that eventually. If I understand it correctly, you would use on 5 h.p. outfit maximum, say 10 h.p. multi-voltage.

MR. FOSTER:—For 50 per cent. variation?

MR. PEARSON:—Yes.

MR. FOSTER:—Yes, we might.

MR. PEARSON:—My idea is that you would use a 20 h.p. motor for the same outfit on the variable speed control, same range of regulation.

MR. FOSTER:—The size of the motors for the three-wire system and the multiple voltage system for the same range in speed, would be the same. In the multiple voltage system, however, this range is carried to a total ratio of 7½ to 1, which would, of course, require a larger motor than the three-wire system, having only a range of 4 to 1.

MR. OSTHOFF:—The discussion would naturally be of those papers presented as to the choice of systems described. Personally, I am inclined to believe that variable speed can be obtained mechanically in most instances, but there do exist cases where an engineer might advocate a variable speed to be obtained in the motor. We offer our system as being the most competent to obtain that end. We claim that the efficiency in the motor is practically as good, the wiring less complicated and a less amount of copper needed, and that the losses outside the motor are less than in the multiple system.

MR. H. R. KING:—In the solution of variable speed problems, it appears that no one system of control can be used to the best advantage in all cases. A variation of speed from full load speed in steps of 10 per cent. to 10 per cent. of the full load speed, the load varying with the speed, is an entirely different proposi-

tion from one, the requirements of which are a constant load with a speed variation of only 25 per cent.

We have a means of speed variation of from 15 to 25 per cent. in standard commercial motors, by means of shunt field regulation, the amount of variation depending on the normal sparkless limit for which the motor is designed. This method of control takes care of a great many propositions where the speed variation is small, while the load on the motor is practically constant. It also has the advantage of using standard motors. Varying the speed by means of varying the field strength, may be carried still farther by using an accumulative compound-wound motor, the series winding being divided, and each section under the control of the operator. We can take this same combination of shunt and series control and place the armature across the varying voltage as is done in several of the systems described to-night. If this armature voltage control is not carried too far, standard motors may be used, providing we do not resort to the sectional series.

In addition to the above arrangements, which give the highest efficiency of operation, we can resort to the armature resistance control—a very inefficient method and one which should not be used except in extreme cases.

I regret very much that no paper has been read on the various mechanical control systems which are now on the market and which are destined to play quite an important part in future speed control problems. They are efficient and generally free from the complications of the electric control.

[Adjourned.]

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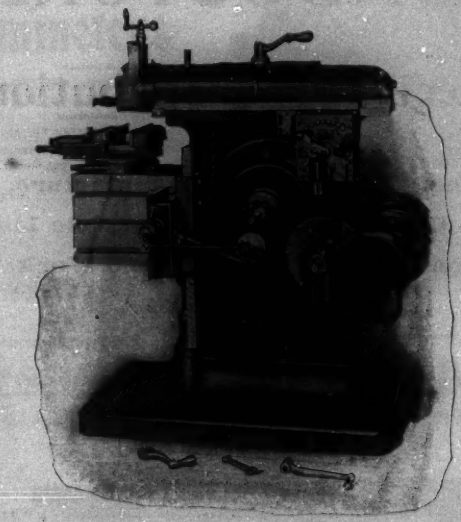

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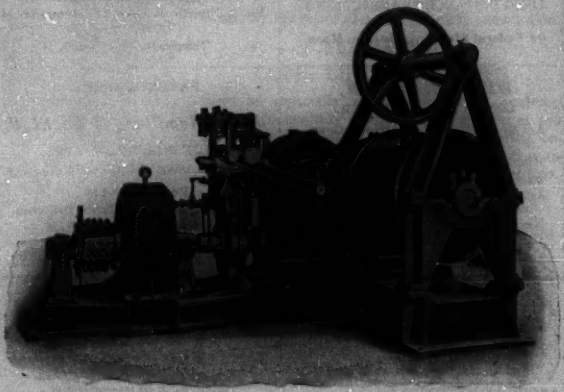

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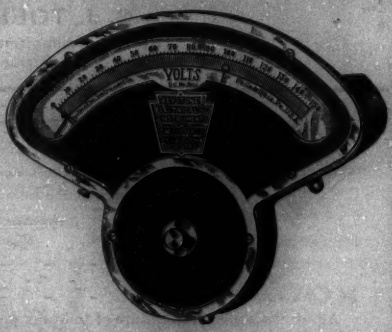

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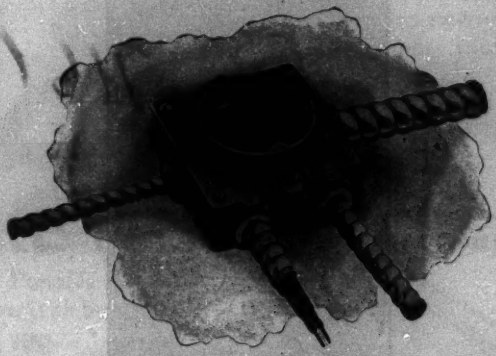

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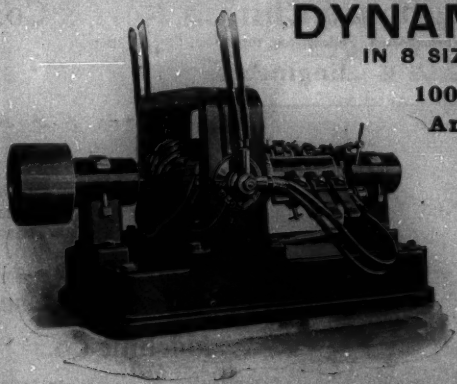

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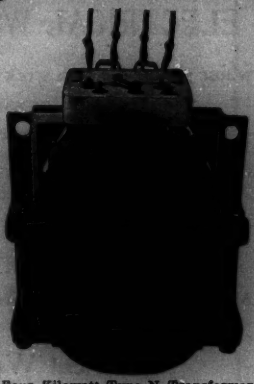

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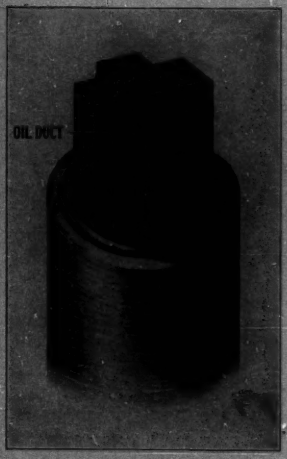
TYPE "H" TRANSFORMERS

CORE TYPE.



In type "H" Transformers, where it would not be economical to limit the thickness of coils to one and one-half inches, ducts for the circulation of cooling oil are provided between the windings and the iron core.

Unequal expansion of transformer windings, which always causes weakening of the mechanical and electrical strength of the insulations can be avoided only when temperatures throughout the windings are maintained perfectly uniform.

It is evident that this uniform heating can exist only when all parts of the windings are at a uniformly short distance from the cooling oil.

Type "H" Transformers —even of the largest size— never have any part of the copper more than one and one-half inches from the cooling oil. Therefore *temperatures and expansions are uniform* in all parts—a result even more desirable than low average temperature.

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